

2003 Space Science Enterprise Strategy

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Review Draft

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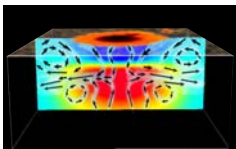
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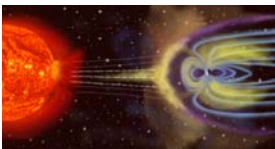
1 **1. INTRODUCTION**

2 NASA’s Space Science Enterprise has achieved remarkable results in our mission to
3 explore the Universe and inspire the next generation. In the three years since the last
4 Space Science Strategic Plan, we have:

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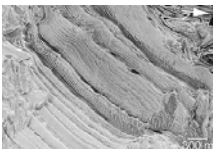
Looked below the Sun’s surface,



Traced the flow of energy from solar flares to the Earth’s atmosphere,



Discovered abundant water ice on the surface of Mars,



Found evidence of sedimentary processes on Mars,



Detected an atmosphere on a planet outside our Solar System,



Seen a supernova 10-billion light years from Earth, and

Discovered that supermassive black holes pervade the Universe.



Tripled the scope of NASA’s space science education and outreach program.

6

7

1 Our programs for the next five years build on these discoveries in the pursuit of answers
2 to fundamental questions. We will search for signs of life elsewhere, as we strive to
3 understand all the term “life” may encompass. We will look for the origins of our
4 Universe including its beginning, its structure, and the formation of our cosmic
5 neighborhood of galaxies, planets and stars. We will learn about our nearest star, the Sun,
6 to understand its effects on our lives and on the evolution of the Solar System. And we
7 will lead the research and technology programs needed to achieve these Objectives.

8 Conveying scientific results to the public is as important as the scientific discoveries
9 themselves. Every program in Space Science Enterprise will continue its commitment to
10 education and public outreach. We will use the unique features of our science to
11 contribute exciting new material to national science curricula and to make the knowledge
12 and wonder accessible to everyone.

13 This five-year Strategic Plan communicates our Strategic Objectives and our processes to
14 achieve them. All of our flight programs, research programs, education and public
15 outreach efforts, and collaborations are defined by and measured against the Objectives
16 laid out in her and in the NASA 2003 Strategic Plan. In short, it is a handbook for what
17 we intend to do and why.

18 The following sections show the traceability of the Enterprise’s Objectives from the
19 overarching NASA Vision, Mission, and Strategic Goals. It describes the practices we
20 use to achieve the Objectives and elaborates on our Science Themes and program
21 elements. The unique content of and tools for our education efforts are also described, as
22 are the technology requirements and development processes. Finally, there is a discussion
23 of our unique resource requirements, including human, capital and information resources.

2. NASA VISION AND MISSION

NASA is embarking on an ambitious adventure of exploration and inspiration. The NASA Vision communicates simply, but powerfully, our mandate in the 21st century. Our Vision is to:

- Improve life here,
- Extend life to there, and
- Find life beyond.

The NASA Mission lays out a clear path to the future. We are called to:

- Understand and protect our home planet,
- Explore the Universe and search for life, and
- Inspire the next generation of explorers...as only NASA can.

This Mission provides a framework for developing goals each part of NASA must achieve. As provided in the Agency strategic plan, NASA has seven Strategic Goals, which enable us to focus planning, manage programs, and measure results. Each of the Agency's six Enterprises—Space Science, Earth Science, Biological and Physical Research, Aerospace Technology, Education, and Space Flight—uses the Strategic Goals to define its programs.

Mission Area	Goal	NASA Enterprise
Understand and protect our home planet.	1. Understand the Earth system and apply Earth system science to improve prediction of climate, weather, and natural hazards.	Earth Science, Space Science , Space Flight
	2. Enable a safer, more secure, efficient, and environmentally friendly air transportation system.	Aerospace Technology
	3. Create a more secure world and improve the quality of life by investing in technologies and collaborating with other agencies, industry, and academia.	Biological and Physical Research, Space Flight, Aerospace Technology, Earth Science
Explore the Universe and search for life.	4. Explore the fundamental principles of physics, chemistry, and biology through research in the unique natural laboratory of space	Biological and Physical Research, Space Flight
	5. Explore the solar system and the Universe beyond, understand the origin and evolution of life, and search for evidence of life elsewhere.	Space Science , Space Flight
Inspire the next generation of explorers.	6. Inspire and motivate students to pursue careers in science, technology, engineering, and mathematics. 7. Engage the public in shaping and sharing the experience of exploration and discovery.	Space Science , Earth Science, Biological and Physical Research, Aerospace Technology, Education, and Space Flight

1

2 Of these goals, the Space Science Enterprise is entrusted with primary responsibility for
3 Goal 5: *To explore the solar system and the Universe beyond, understand the origin and*
4 *evolution of life, and search for evidence of life elsewhere.* We also support the first Goal,
5 and the education and public outreach Goals (6 and 7). These collaborations visibly
6 implement the “One NASA” management concept for the Agency.

3. SPACE SCIENCE OBJECTIVES

NASA's Strategic Goals are very broadly stated. To enable the Space Science Enterprise to plan, manage, and measure progress, the Agency Goals are further broken down into Enterprise Objectives.

The external space science community guides the formulation and articulation of the Enterprise Objectives. Independent studies of the status of scientific knowledge in key areas are performed by the National Research Council, which also provides recommendations for future investigations. Based in part on the National Research Council inputs, the Enterprise's Space Science Advisory Committee and its discipline subcommittees identify high-priority science objectives and postulate a program of flight missions to address the objectives.

The Enterprise integrates these inputs—considering also such factors as technology readiness and resource projections—and formulates an integrated program of flight missions, technology development and scientific research. The consolidated Enterprise Objectives document consensus on priorities and are used as a reference for selection of investigations and other programmatic decision making, as input to the NASA Strategic Plan and Government Performance and Results Act (GPRA) assessments, and as tools for program and budget advocacy.

The programs and tasks implemented to meet Enterprise Objectives are funded through five Space Science Themes, which provide the structure for budget planning, management, and performance reporting. Every program implemented to meet the Enterprise Objectives is managed and budgeted within these Space Science Themes.

Education and public outreach are so important to NASA's overall Mission that a separate set of Strategic Goals has been established for them. Every Space Science Enterprise program contributes actively and directly to Enterprise Objectives that support the Agency's education Goals. Management and funding of these activities are distributed throughout the Themes.

Agency Strategic Goal	Space Science Enterprise Objective	Space Science Theme
1. Understand the Earth system... to improve prediction of climate, weather, and natural hazards.	Understand the origins and societal impacts of variability in the Sun-Earth Connection.	Sun-Earth Connection
	Catalog and understand potential hazards to Earth from space	Solar System Exploration
5. Explore the solar system and the Universe beyond,	Learn how the solar system originated and evolved to its current diverse state.	Solar System Exploration
	Determine the characteristics of the solar system that led to the origin of life.	

understand the origin and evolution of life, and search for evidence of life elsewhere.	Understand how life begins and evolves.	
	Understand the current state and evolution of the atmosphere, surface, and interior of Mars.	Mars Exploration
	Determine if life exists or has ever existed on Mars.	
	Develop an understanding of Mars in support of possible future human exploration.	
	Understand the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments.	Sun-Earth Connection
	Understand the fundamental physical processes of space plasma systems.	
	Understand how today's Universe of galaxies, stars, and planets came to be.	Astronomical Search for Origins
	Learn how stars and planetary systems form and evolve.	
	Understand the diversity of other worlds and search for those that might harbor life.	
	Discover what powered the Big Bang and the nature of the mysterious dark energy that is pulling the Universe apart.	Structure and Evolution of the Universe
	Learn what happens to space, time, and matter at the edge of a black hole.	
	Understand the development of structure and the cycles of matter and energy in the evolving Universe.	
6. Inspire and motivate students to pursue careers in science, technology, engineering, and mathematics.	Improve student proficiency in science, technology, engineering and mathematics by creating a culture of achievement, using educational programs, products, and services based on NASA's unique missions, discoveries, and innovations.	All Themes
	Motivate K-16+ students from diverse communities to pursue science and math courses and, ultimately, college degrees in science, technology, engineering, and mathematics.	
	Enhance science, technology, engineering, and mathematics instruction with unique teaching tools and experiences that only NASA can provide, that are compelling to educators and students.	
	Improve higher education capacity to provide for NASA's and the Nation's future science and technology workforce requirements.	
7. Engage the public in shaping and sharing the experience of exploration and discovery.	Improve the capacity of science centers, museums, and other institutions through the development of partnerships, to translate and deliver engaging NASA content.	All Themes
	Engage the public in NASA missions and discoveries through avenues in public programs, community outreach, mass media, and the internet	

- 1 The search for life requires a new understanding of what life is, its origins, where it can
- 2 exist. This search addresses the multiple scientific disciplines available throughout
- 3 NASA and our diverse scientific community. The Space Science Enterprise leads and
- 4 manages the Astrobiology Program for the Agency, a unifying theme and key contributor
- 5 to the NASA Vision and Mission.

4. ACHIEVING SPACE SCIENCE OBJECTIVES

The Space Science Enterprise achieves its Objectives through flight missions and ground-based scientific research and data analysis. The interplay and iteration between flight missions and supporting research is the source of vitality for the whole program.

All Space Science activities are funded through and managed within the Themes using standard processes designed to conduct business fairly and consistently across the Enterprise. In addition, there are overarching Space Science principles that govern the decision-making process.

This section will describe the principles, processes and programs that enable us to achieve our Objectives. For the purpose of managing program activities, the Enterprise further breaks the Strategic Science Objectives down into Research Focus Areas. These areas are summarized within the Theme Program discussions, and the full structure is provided in the appendix.

4.1 Program Elements

Space science investigations are very diverse, but the Enterprise applies standard processes to conduct them. For example, the Enterprise applies a uniform approach to selecting and implementing the individual flight projects in every Theme program. Supporting research and analysis cover an enormous breadth of topics, as do technology development and demonstration activities, but they too are managed to the extent possible in a consistent way. Education and public outreach, important mandates for the space science program, seek efficiencies by adopting common strategies and organizational approaches across the Enterprise.

4.1.1 Flight Missions

The Space Act of 1958 established NASA as a mission agency that sponsors and conducts flight missions to obtain data in furtherance of its objectives. These flight missions range from suborbital projects—including balloons, sounding rockets, and airplanes—to interplanetary probes and flagship observatories. In executing its flight missions and obtaining these data, the Enterprise uses a consistent approach to selecting and executing flight missions.

First, all investigations selected and missions flown must respond to Agency Goals and Enterprise Objectives. In some cases, mission science objectives and requirements are specified by the Enterprise based on the strategic planning process, and instrument investigations to meet these requirements are solicited from the scientific community. In other cases, often called “community-based” missions, Principal Investigators from the scientific community form teams to propose entire missions, from basic science requirements through mission operations and science data analysis after launch. These teams often include universities, industry, implementing laboratories, and NASA Centers.

Space Science Enterprise programs are firmly anchored in the Agency Strategic Goals and Enterprise Objectives. We combine consecutive missions that address a cluster of science objectives into “mission lines.” These mission lines enable us to fly successive missions as science

priorities dictate and as resources and technology permit. Among the mission lines are the Discovery Program, which comprises Solar System Exploration and Origins missions; Mars Scout, which includes regular opportunities for

NASA's Explorer program is an example of mission lines that are vital to realizing the Enterprise's science objectives. Explorer offers frequent opportunities to carry out small- and medium-sized missions (SMEX and MIDEX) that can be developed and launched in a short (approximately four-year) time frame. These focused missions can address science of great importance to several of the Themes and respond quickly to new scientific and technical developments. The Mission of Opportunity option enables valuable collaborations with other agencies, both national and international. Explorer Missions and Missions of Opportunity are selected for science value through competitive peer review.

Each Explorer solicitation elicits more high-quality experiments than can be implemented. Peer review, the ability to implement new, creative ideas, and quick reaction to recent discoveries are essential elements of the high science value of the Explorer program.

innovative research in support of Mars Objectives; New Frontiers, a new line for planetary exploration; and Explorer (see inset). These are some of the most successful programs within NASA and are the model for future missions.

The Enterprise encourages broad participation in all of its flight missions by outside industry and the academic community. Foreign partners are also invited to participate on a no-exchange-of-funds basis. A fundamental premise of the Enterprise's approach to implementing all aspects of its program is open and competitive merit selection. That is, opportunities are open to all proposers, within fixed rules, via public announcement, and selections are based primarily on science and technical merit as evaluated by independent peer review. Another premise is that instrument development and mission implementation are managed to fixed performance requirements and cost caps. Finally, extension of a mission's operation beyond its funded baseline is determined on the basis of a competitive selection based on past and prospective scientific productivity of the mission compared to other ongoing missions.

4.1.2 Scientific Research and Analysis

The Space Science Enterprise sponsors a rich program of scientific research and technology development to achieve its Objectives. While a larger share of the Enterprise's total resources is expended on flight mission design and execution, ground-based activities play an essential role. Theoretical, modeling, and laboratory work provide invaluable tools to understand and integrate measurements made in space and on the ground and can also directly impact future missions. Innovative space measurements are not possible without advanced detector and instrument systems, most of which are developed through Enterprise grants programs. Many of these future space flight instruments are first tested in the suborbital sounding rocket and balloon programs. The Enterprise also supports the development and flight demonstration of spacecraft subsystems necessary to advance the capabilities of its spacecraft. To fully exploit scientific data obtained from missions to address science Objectives, scientists must analyze and interpret them. The quantity and diversity of data returned from space

science missions continue to grow, and the Enterprise supports operation of systems for their analysis, management, and investigator access, as well as design and implementation of the next generation of these data systems.

Exciting new revelations about the cosmos are not possible without the most **advanced detector and instrument systems** that can be built. Most of these are developed under sponsorship from space science R&A programs. A multi-faceted approach is needed to develop more efficient detectors in all wavelength and energy ranges. For example, the study of star and planet formation, interstellar dust, and very distant dusty objects calls for innovative detectors in the infrared and submillimeter portion of the spectrum. Major strides in the studies of those aspects of dark matter and baryons, the origin and evolution of elements, and major construction phases of galaxies and quasars require observations in the ultraviolet and optical wavelength that can be made only when there are significant advances in detector technology. For example, determining the fate of matter as it falls into a black hole requires the development of hard X-ray imaging detectors. Large-format arrays and energy-resolving detectors are needed to make simultaneous two-dimensional spectral imaging observations of high-temperature plasmas.

The latest detectors for the Hubble Space Telescope, the Chandra X-ray Observatory, Solar and Heliospheric Observatory (SOHO), and the Space Infrared Telescope Facility (SIRTF) were developed largely within the R&A program. Future generations of instruments slated for possible use on Explorer, Discovery, and other strategic missions, are now being developed within the R&A program. Detectors and instruments developed in the R&A programs are frequently tested under real-life conditions in the **sounding rocket and balloon** programs before they are selected to fly on much more expensive Earth-orbiting and deep space spacecraft.

Ground-based programs are particularly valuable in supporting preparations for new missions, for testing new technologies, for investigating new observing strategies, and for providing data to test new analysis techniques. For example, cosmic microwave background experiments will pave the way for a mission aimed to detect gravitational wave signatures produced by quantum fluctuations of space-time during inflation; an inventory of nearby planets is crucial to the design of the TPF mission; and ground based observing systems provide the global context of the ionosphere and upper atmosphere for magnetospheric and ionosphere-thermosphere-mesosphere missions. One of most effective near-term methods to carry out observations directed towards addressing the dynamics and composition of near-Earth objects, other asteroids, and Kuiper Belt objects is with large ground based telescopes.

The **Astrobiology** R&A programs have been at the forefront of an effort to break down discipline barriers to promote vigorous research at the boundaries between traditional scientific disciplines. Astrobiology program span a wide range of investigations, including understanding the nature and distribution of habitable environments in the Universe; exploring for past or present habitable environments, prebiotic chemistry, and signs of life elsewhere in our Solar System; understanding how life emerges from cosmic and planetary precursors; understanding how past life on Earth interacted with its changing planetary and Solar System environment; understanding the evolutionary mechanisms and environmental limits of life; understanding the principles that will shape

the future of life, both on Earth and beyond; and determining how to recognize signatures of life on other worlds and on early Earth

Astrobiology is multidisciplinary in its content and interdisciplinary in its execution.

Four openly competed, complementary programs provide the mechanism and intellectual foundation to prepare for and guide future space exploration opportunities.

- The exobiology/evolutionary biology program focuses individual investigator research on the origins and evolution of life, using the Earth as a benchmark against which the potential for life in the galaxy is to be measured.
- The NASA Astrobiology Institute, an institute-without-walls, enables concentrated science collaboration by expert teams located across the US and world answering fundamental questions in astrobiology.
- An instrument development program encourages concept to “brass-board” development of astrobiology-specific instruments capable of operating in space and extraterrestrial environments.
- A program of science-driven robotic explorations of extreme environments expands our understanding of life on Earth and improves our capacity for semi-autonomous operations when exploring other planetary bodies.

As part of its fundamental principles, Astrobiology encourages planetary stewardship through an emphasis on protection against forward and back biological contamination and recognition of ethical issues associated with exploration. In addition, Astrobiology appreciates that a broad societal interest in its endeavors offers a crucial opportunity to educate and inspire the next generation of scientists, technologists and informed citizens. Thus, there is a strong emphasis on education and public outreach in Astrobiology.

Laboratory measurements can provide the essential link between observations and scientific conclusions. The Laboratory Astrophysics program impacts a tremendous breadth of topics, from the coldest regions deep in molecular clouds to the extraordinary environments around supermassive black holes. Furthermore, laboratory experiments have shown that some of the raw materials for life can be created in interstellar grains of ice and dust. It is vital to continue these experiments, as well as others aimed at understanding potential signatures of life that could be detected on Earth-like planets, spectroscopically, from space missions. Techniques are being developed for curating and analyzing extraterrestrial material in the form of returned samples of cometary dust, solar dust, and eventually from Mars. Maintenance and upgrades of existing facilities are essential components of this effort.

Supporting technologies, such as lightweight mirrors, optical coatings, gratings, and solar blind filters, are developed to the level of laboratory-demonstration models. The evolution of measurement capabilities influences our priorities for starting and launching future space missions. Thus, this R&DA component also has a direct influence on mission planning.

The roles of **modeling, theory and laboratory** work lie in **analysis and interpretation of data** returned by NASA’s space science missions, to exploit them fully for achieving strategic Objectives, and to predict **observable and measurable phenomena** that drive

future mission, spacecraft, and payload design requirements. Some areas that require additional theoretical development are: models that support directly the search for extrasolar planets; simulations of black hole environments; models of the large-scale structure of solar corona; fundamental plasma models that are needed to prepare and execute missions; basic physical understanding needed to create space weather forecasting capabilities; cosmic evolution of biogenic compounds; the early evolution of life; planetary protection; and theoretical tools for extracting and interpreting essential science from observational data.

Vast amounts of data are returned from space science missions. There are growing opportunities for data analysis made possible by the volume, richness, and complexity of these data, as well as the ability to integrate and correlate data from multiple missions into a larger context. Exploration and discovery using widely distributed, multi-terabyte datasets will challenge all aspects of **data management** and rely heavily on the most advanced analysis and visualization tools. The design and implementation of the next generation of information systems will depend on close collaboration between space science and computer science and technology. An example of such collaboration is the National Virtual Observatory (NVO) initiative to integrate most of the nation's astronomical data to support “observations” and discovery via remote access to digital representations of the sky. This concept is national in scope across institutions and federal agencies and virtual in that it is not tied to any physical location. A new type of general-purpose observatory, the NVO will enable scientific discovery through innovative data access and computational tools. A similar program, the Virtual Solar Observatory, will facilitate access to the best available solar data.

Components of the R&DA Program

Each science Theme sponsors Research and Data Analysis (R&DA) programs that provide opportunities to develop new ideas, concepts, and methods, and to analyze and interpret data from space science missions. R&DA is crucial to the space science community, because ideas developed here often form the basis for new mission concepts. Its strong university involvement provides the additional benefit of training graduate students and the builders of future space missions; veterans of the R&DA program often become Principal Investigators of flight missions and major instrument builders.

Role of NASA’s Research and Data Analysis Programs

Critical functions of the R&A programs identified by the Space Studies Board are:

- Theoretical investigations
- New instrument development
- Exploratory or supporting ground-based and suborbital research
- Interpretation of data from individual or multiple space missions
- Management of data
- Support of U.S. investigators who participate in international missions
- Education, outreach, and public information

The R&DA program has two major components. The first, Research and Analysis (R&A) includes experimental research—such as detector/instrumentation development,

1 suborbital flights, and laboratory astrophysics—that creates tools for new and better
2 scientific investigations. The R&A program consists today of nine “science clusters” that
3 serve the scientific disciplines of astrophysics, space physics, and planetary research.

4 The second, Data Analysis (DA), supports interpretive research—including theory,
5 modeling, observations, and data analysis—that leads to discoveries and predicts new
6 directions for future scientific investigations. Work in this program is performed by
7 mission instrument teams and interdisciplinary scientists competitively selected to
8 participate on an individual mission for the lifetime of the mission. In addition, there are
9 periodic open and competitive solicitations to support participation by other community
10 investigators in analysis of data from these missions. DA support for investigations
11 beyond a mission’s baseline operation is determined through a competitive senior review
12 process.

13 All R&DA programs are competitively selected.

14 ***4.1.3 Technology Development and Validation***

15 Objectives

16 Our technology program pursues three key objectives. First, we strive to develop new and
17 better technical approaches and capabilities in response to needs established for space-
18 based scientific measurement systems. Where necessary, we then validate these
19 capabilities in space so that they can be confidently applied to science flight projects.
20 Finally, we apply these improved and demonstrated capabilities in the science programs
21 and ultimately transfer them to U.S. industry for public use.

Enterprise Technology Objectives	Enterprise Technology Actions
Acquire new technical approaches and capabilities	<ul style="list-style-type: none"> • Focus technology development on a well-defined set of performance requirements covering the needs of near-term to mid-term strategic plan missions (“mission pull”) • Establish long term technology development goals through systems analysis of visionary missions and guide basic technology research to meet projected long-range needs (“vision pull”) • Pursue a closer collaboration with the Aerospace Technology Enterprise and develop innovative approaches for effective “infusion” of technology • Fund new technologies via broad and open competition wherever appropriate • Promote partnerships with other agencies, industry, academia, and foreign collaborators to take advantage of capabilities developed elsewhere
Validate new technologies in space	<ul style="list-style-type: none"> • Identify technologies of high value to future Enterprise missions and fund their development to the point that they are ready for ground or space demonstration • Formulate, develop, and implement cost-effective space demonstrations of selected technologies on suitable carriers through partnerships, cooperative agreements or direct funding
Apply and transfer technology	<ul style="list-style-type: none"> • Use new technologies, in multiple missions where possible, to reduce costs, shorten mission development time and increase reliability across the program • Maximize benefits to the Nation by stimulating cooperation with industry, other Government agencies, and academia in collaboration with the Technology Commercialization Division

The complete Enterprise Technology Implementation Strategy, issued as a separate Enterprise document, describes how the technology objectives are achieved. This approach is summarized here.

Acquiring new technical approaches and capabilities. When mission concepts are defined sufficiently to begin detailed scoping of their instrumentation, systems and infrastructure performance requirements are derived. Technology development is focused on satisfying these requirements (“mission pull” technologies).

Less-mature technology research (“vision pull”)—often pursued in close collaboration with the Aerospace Technology Enterprise (ATE)—is focused on more general measurement challenges. These are formulated, on the basis of priorities established by the National Academy of Sciences and by study groups who work with the science and technology communities. The challenges are designed to stimulate the breakthrough innovation that will enable new measurement approaches and mission concepts. Two recent initiatives (*In-Space Propulsion* and *Project Prometheus*) are particularly noteworthy examples of “vision pull” technologies derived from advanced studies. The balance between “mission pull” and “vision pull” aims to assure the adequacy and resiliency of the technology available to future science missions.

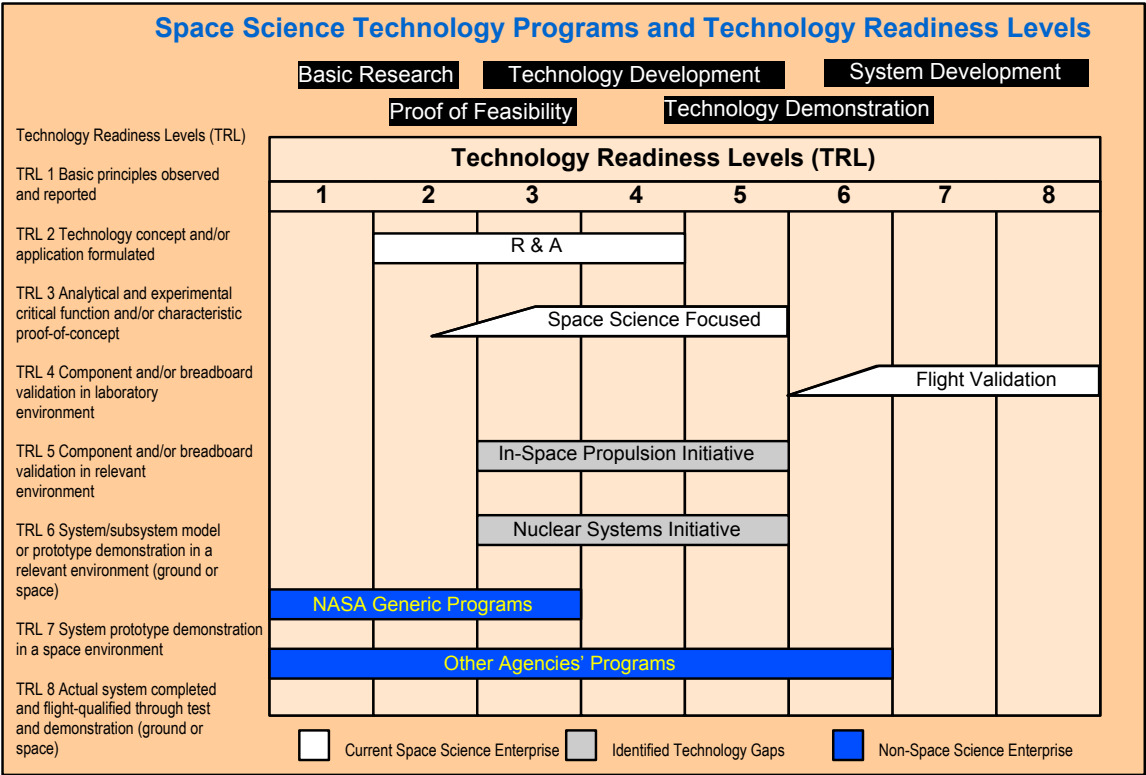
We value many of the technologies pursued by the Aerospace Technology Enterprise, and our missions have often benefited from their early development of innovative

1 concepts. A goals are to implement the One NASA policy through collaboration with
2 ATE and to enhance the value of this collaboration by developing new relationships and
3 formal processes for communicating technology requirements in a more precise and
4 timely fashion. We are also establishing new practices along with ATE to shepherd—and
5 winnow—lower-maturity technology toward efficient infusion into our flight missions.

6 Space science continues to be a powerful inspiration for engineers and technologists
7 everywhere: we seek to take advantage of this large talent pool by advertising widely the
8 opportunities of our openly competed programs and by encouraging the formation of
9 partnerships between the implementing centers and the innovators in universities,
10 industry and other government agencies. While conducting cooperative activities in
11 technology the Enterprise protects proprietary data and intellectual property.

12 **Validating new technologies in space.** The large number of technologies that are at a
13 medium level of maturity are examined periodically to identify those promising
14 candidates that could add significant value to future missions if convincingly
15 demonstrated in an operational setting. These concepts are then selected competitively
16 and are funded for space validation principally through the New Millennium Program and
17 also through flight of opportunity missions. Ground validation of technologies not
18 requiring space flight validation is accomplished through the focused technology
19 programs of the space science Themes.

20 **Applying and transferring technology.** The technical requirements of the missions are
21 often unique, due to the nature of the scientific undertaking. Nevertheless, by comparing
22 requirements, we systematically seek the efficiency that derives from identifying
23 common needs, and occasionally by aligning mission requirements, that may be met by a
24 coordinated technology development and application. This results in reduced mission
25 costs and shortened development time across the programs.



Management practices

Management of the technology life cycle for strategic, NASA-formulated missions begins with the science **Theme roadmaps**. The Enterprise allocates resources in the focused technology programs, defines solicitation topics in the Small Business Innovation Research program, establishes priorities for the New Millennium Program and proposes candidate topics for the space technology program managed by the Aerospace Technology Enterprise. The Research and Analysis program’s yearly research solicitation also reflects the priorities established by the theme programs.

Funding technologies through **broad and open competition** ensures that the most innovative ideas, the most competent individuals and groups, and the widest participation will foster the most productive research. Such competition will also enhance the opportunities for space science-funded technologies to be transferred to academia and private industry for the benefit of the nation.

We maintain the **quality of our Enterprise’s technology** development efforts by means of rigorous peer selection and review, and through monitoring by external groups convened to review specific technology programs. The **Technology Steering Group** uses a variety of tools to determine the relative benefits and costs of alternative technologies, both those developed internally and those provided by university and industry participants. The Steering Group contributes to the yearly update of the NASA Technology Inventory and summarizes the status of this work semiannually in the “**OSS Technology Blueprint**.” On the basis of these external and internal reviews and reports, the Enterprise Management considers reallocation of resources every year during the budget development process.

Technology infusion into the community-formulated missions in the Explorer, Discovery and New Frontiers programs occurs by a different path, since missions in these programs are proposed as integrated packages by the research community and proceed directly to detailed definition without the benefit of a lead-in technology development program. The selecting official has the option of allocating a small amount of technology funding for a proposal of scientific merit that is not otherwise selectable because of insufficient technological readiness. In addition, Research and Analysis programs offer competitive opportunities primarily for development of instruments in selected areas. Finally, technology developments supported under the Focused Technology Programs for the NASA-formulated missions also become available to proposers in the community-formulated programs.

4.1.4 Education and Public Outreach

By engaging the imaginations of teachers, students, and the general public, space science has demonstrated extraordinary potential for strengthening interest in science and improving the quality of science, technology, engineering, and mathematics, and education in America. By attracting bright individuals to advanced study in technical fields, space science also plays a significant role in ensuring a continuing cadre of trained scientists, technologists, and engineers to meet our society's needs in the 21st century.

The Space Science Enterprise has developed an extensive education and public outreach program that is aligned with and strongly supports the NASA mission to “inspire the next generation of explorers.” Consistent with NASA priorities, the two main elements of our education and public outreach program are to “inspire and motivate students to pursue careers in science, technology, engineering, and mathematics” by supporting education in the Nation's schools and to “engage the public in shaping and sharing the experience of exploration and discovery” by supporting informal education and public outreach efforts. Our program emphasizes sharing the results of our missions and research programs with wide audiences and using space science discoveries as vehicles to improve teaching and learning at all levels. Our commitment to education places a special emphasis on pre-college education, diversity, and increasing the general public's understanding and appreciation of science, technology, engineering, and mathematics. This emphasis complements our traditional role in higher education, where we will continue to support professional education through research involvement as a central element of meeting our responsibility to help create the scientific and engineering workforce of the future.

Education and Public Outreach Implementation Approach

There are a set of fundamental principles we use in planning and evaluating space science E/PO activities. We ensure that a substantial, funded education and outreach program is incorporated into every space science flight mission and research program and consistently increase participation of the space science community contributing to a broad public understanding of science and directly involved in education at the precollege level. Because of our commitment to contribute as only NASA can, we sustain and expand strong and lasting partnerships between the space science and education communities. We also operate and maintain a national network to identify high-leverage education and outreach opportunities and to identify and sustain long-term partnerships between scientists and educators. To increase availability of our material, we provide

1 organized, ready access to the products of space science education and outreach program.
2 We also provide opportunities for participation in the space science program by an
3 increasingly diverse population, including opportunities for minorities and minority
4 universities to compete for and participate in space science missions, research, and
5 education programs. Finally, we evaluate the quality and impact of all space science
6 education and outreach programs

7 The Space Science Enterprise approach to supporting NASA's education and public
8 outreach goals and objectives is based on our policy of incorporating education and
9 public outreach as an integral component of all of our activities, both flight missions and
10 research programs. Contributing to education and outreach is the collective responsibility
11 of all levels of Enterprise management and of all participants in the space science
12 program. Space science mission personnel and researchers, in particular, are encouraged
13 to become active participants in education and outreach activities. We focus on
14 identifying and meeting the needs of educators and on emphasizing the unique
15 contribution NASA space science can make to education and the public understanding of
16 science.

17 With limited resources, leverage is key to building a national program that contributes
18 both to improving teaching and learning at the pre-college level and to increasing the
19 scientific literacy of the general public. The Enterprise achieves this leverage in pre-
20 college education by building on existing programs, institutions, and infrastructure and
21 by coordinating activities and encouraging partnerships with other ongoing education
22 efforts. We have also established alliances for informal education with science centers,
23 museums, and planetariums, as well as with producers of public radio and television
24 programs, and we are experimenting with new ways to bring the results of the space
25 science program to teachers, students, and the public through partnerships with
26 community organizations of many different types across the country. In all of these
27 partnerships, we seek to provide space science content and expertise while relying on our
28 partners to provide the educational expertise and context.

29 To improve the effectiveness of our education and public outreach program, we operate a
30 national space science support network that seeks out, develops, and sustains high-
31 leverage partnerships, helps the space science community become involved in education
32 and outreach; and ensures that products and programs developed locally become national
33 resources. We make our educational products readily available to educators through an
34 online education resource directory that is linked to other NASA and national databases
35 of educational materials. We provide opportunities for participation in space science
36 programs by an increasingly diverse population through emphasizing inclusiveness in all
37 of our education and public outreach efforts and by developing special opportunities for
38 minority students and educators, minority institutions, students with disabilities, and
39 other targeted groups to participate in the space science program. Finally, we seek expert
40 feedback on quality and impact through a variety of means including peer review,
41 evaluation by an external evaluation group, and through other focused efforts directed
42 towards providing third-party advice on the quality and overall direction of the program.

43 Since the previous Enterprise Strategic Plan was released in 2000, our education and
44 public outreach efforts have reached a very visible level of maturity. Funded education
45 and public outreach programs are embedded in all of our missions and research

1 programs; partnerships have been established with hundreds of local, regional, and
 2 national institutions and organizations; and thousands of education and public outreach
 3 events are taking place annually throughout the Nation.

4 Future Efforts

5 Our future education and public outreach efforts will build on these activities and
 6 accomplishments with an emphasis on improving their quality and impact, and on
 7 extending their reach into new areas. For example, we will:

- 8 • Continue to contribute to the professional training of scientists by supporting
 9 research assistantships and post-doctoral opportunities offered through OSS
 10 research awards and through other NASA research and higher education
 11 programs.
- 12 • Coordinate our education and public outreach program with other similar efforts
 13 being undertaken throughout NASA in order to optimize our contribution to the
 14 Agency's overall education program.
- 15 • Provide opportunities for students to work directly with NASA space science
 16 missions, facilities, and data. Such opportunities are particularly important for
 17 precollege students, where the experience of being involved in a NASA mission
 18 or research program can easily inspire career choices and life-long interests.
- 19 • Increase our efforts to provide opportunities for an increasingly diverse
 20 population to participate in space science missions, research, and education and
 21 outreach programs. We will continue and expand our efforts to develop space
 22 science capabilities at minority institutions, and we will develop and enhance
 23 partnerships with special interest organizations such as professional societies of
 24 minority scientists to provide new avenues for reaching and involving diverse
 25 populations. We will develop working partnerships and coordinate with the
 26 diversity initiatives of scientific professional societies, and we will extend the
 27 accessibility of space science E/PO programs and products to an increasingly
 28 broad population, including such groups as girls, and residents of rural areas, and
 29 persons with disabilities.
- 30 • Improve the coherence of NASA space science materials for educators by
 31 building a framework that will show the appropriate standards-aligned sequencing
 32 of space science topics throughout the K-12 years and will provide overall
 33 direction and context for the materials being produced by individual missions.
- 34 • Build on strong mutual interests between the Space Science Enterprise and the
 35 science center, museum, and planetarium communities by continuing to provide
 36 space science content, materials, and technical expertise to support the
 37 development of exhibitions and programs. We will also explore new areas such as
 38 partnerships with children's museums to engage younger children in science
 39 activities; methods for bringing near real time images and data to science centers,
 40 museums, and planetariums; and opportunities for training science center,
 41 museum, and planetarium staff in current space science missions and discoveries.

- 1 • Enrich the science, mathematics, engineering, and technology educational efforts
2 of community groups such as the Girl Scouts, 4H Clubs, and Boys and Girls
3 Clubs through the introduction of space science.
- 4 • Take advantage of the advanced-technology nature of much of the Space Science
5 Enterprise's program to develop new materials and new programs in technology
6 education
- 7 • Provide coherent and sustained professional development to all personnel
8 engaged in NASA space science education and public outreach in order to
9 increase the effectiveness of their work in education.
- 10 • Extend and deepen previous work on educational evaluation to more fully
11 understand the impact of the OSS E/PO effort, and continue to use the results of
12 assessment and evaluation studies to improve the quality of OSS E/PO programs.
- 13 • Seek out and capitalize on special events and particularly promising opportunities
14 in our scientific program to bring space science to and involve the public in the
15 process of scientific discovery and to use space science to improve science,
16 engineering, mathematics, and technology education at all levels. Such
17 opportunities arise naturally from within our missions and science programs, and
18 they are discussed in the context of each research theme in the sections that
19 follow.

20

4.2 Science Themes

Management and implementation responsibility for the Enterprise's broad research program are allocated among five Themes: Solar System Exploration, Mars Exploration, Sun-Earth Connection, Astronomical Search for Origins, and Structure and Evolution of the Universe. Each Theme aggregates related science objectives and activities, including flight missions and supporting research and technology development. The Themes are, in turn, managed by one of the three Enterprise divisions or a program office. These line organizations are responsible for managing the Enterprise's budget resources.

Overlap and cross-fertilization of scientific questions and research occurs between Themes, an interaction that has proven to stimulate scientific innovation. In the Themes, definition, selection and management of supporting research and flight projects are carried out according to uniform Enterprise practices. Education and public outreach are considered an integral part of the Enterprise program, and all activities include a budgeted education or public outreach component.

Solar System Exploration and the Public (Sample E/PO Facing Page)

As the Solar System Exploration theme seeks to understand how our own solar system formed and evolved, it will also explore innovative methods for delivering curriculum content materials to teachers. Rather than inundating teachers with an overwhelming mix of materials from each new mission, we will organize and package the materials along story lines that coincide with national science education standards.

For example, understanding the general structure of the Solar System, the ways in which the planets and their moons are both similar to and vastly different from each other, and the processes by which the solar system and its planets formed and evolved are topics that build sequentially throughout the elementary and secondary school years. We will build a curriculum framework that addresses this sequence in a coherent manner and uses the discoveries from current and future Solar System Exploration missions to fill in and continually revise the content and materials at available at each step in the sequence.

The quest to better understand natural hazards leads, among other things, to the study of volcanoes. Here we can provide supplementary materials that survey and compare volcanic activity throughout the solar system and tie them to a curriculum framework that sequentially builds an understanding of processes that shaped the Earth

Suggested illustrations:

Volcanic eruption on Io: Mars with volcanoes:



Olympus Mons, the largest known volcano in the Solar System

4.2.1 Solar System Exploration

Our solar system is a place of beauty and mystery, incredible diversity, extreme environments, and continuous change. It is also a laboratory that we can use to unlock mysteries of the origins of life and our place within the universe. The planets and the ancient icy bodies that reside far from the Sun are Rosetta Stones that encode our own system's history and inform our understanding of how other planetary systems formed and how prevalent planets around other stars may be. Our Sun's planets have numerous moons, with diverse characteristics, that tell their own story about the evolution of our solar system. As we discover more about these moons, and about the origins of living systems, we may learn that life once arose or still exists on some of them. NASA's Solar System Theme has three Objectives.

Objective: Learn how the solar system originated and evolved into its current diverse state.

Within the first billion years of their history, the planets of our solar system formed and life began to emerge on Earth and, perhaps, elsewhere. Many of the current characteristics of the solar system emerged during this critical formative epoch. However, the tremendous changes that Earth and the planets have undergone over the intervening eons have erased most of the physical records of this period, so our knowledge of it is only fragmentary.

Fortunately, vital clues are scattered throughout the solar system. The Moon's South Pole Aitken Basin is expected to offer the oldest rocks that are accessible for detailed geochemical analysis. The surface and environment of Mercury will yield clues to conditions in the innermost parts of the solar nebula and to the processes that formed the inner planets. The interior structure and chemical composition of Jupiter can illuminate the processes that formed the giant planets. The Pluto/Charon system and the Kuiper

New Frontiers, a New Mission Line for Exploration

New Frontiers is a mission line dedicated to ambitious Solar System Exploration. The principal objective of the New Frontiers Program is to provide regularly scheduled opportunities for high quality, cost effective scientific investigations that fulfill the Solar System Exploration Objectives. In keeping with Enterprise practices, these missions will be competitively selected through peer reviewed-proposals.

Following the recent publication by the National Research Council of the Decadal Solar System Exploration Survey, entitled *New Frontiers in the Solar System: An Integrated Exploration Strategy* the Space Science Enterprise identified four medium-class missions for immediate consideration for this first opportunity within the New Frontiers Program. These four "strawman" missions are, in no order of priority:

- 1) Venus *in situ* explorer;
- 2) Lunar South Pole Aitken Basin sample return mission;
- 3) Jupiter polar orbiter with Probes; and
- 4) Comet surface sample return mission.

In addition, New Frontiers may solicit proposals for a Europa geophysical explorer mission, identified as the top priority in the large mission category by the Decadal Survey.

Belt are expected to preserve the best records of the volatile and organic materials that were present in the original solar nebula. The Kuiper Belt is also the birthplace of the short-period comets that may have delivered volatile and organic materials (*e.g.*, water) to the inner planets.

The underlying physical, chemical, geological and biological processes of the bodies in our solar system interact in complex and surprising ways. For example, after the epoch of planet formation, the evolutionary paths followed by each of the inner planets led to dramatically different outcomes. We will study this interplay of processes to understand how they shaped the solar system and can affect potential habitats for life.

Comprehensive comparative studies of the atmospheric chemistry, dynamics, and surface-atmosphere interactions on Mars and Venus will yield insight into to the evolutionary paths these planets followed, and their implications for the Earth.

Finally, it has become increasingly clear that exploration of our solar system will tell us much about the formation of extrasolar planetary systems. Conversely, characteristics of extrasolar systems will also inform our understanding of our own home system – and may give us insight into how typical our solar system might be.

MESSENGER, a Discovery mission currently in development, will conduct comprehensive geophysical and geochemical investigations of Mercury.

Deep Impact, another Discovery mission in development, will investigate volatile and organic materials in the deep interior of the nucleus of short-period comet

Finally, competitively selected New Frontiers missions will be solicited to address this Objective.

Objective: Determine the characteristics of the solar system that led to the origin of life.

The essential requirements for life as we know it are a source of usable energy and basic nutrients, organic material, and liquid water. The availability of all of these ingredients defines what is called a “habitable zone.” It was once thought that the habitable zone of our solar system is limited, primarily by solar energy, to a fairly narrow region around Earth’s distance from the Sun. On the Earth, habitable environments were thought to be limited to regions on or near the surface where temperature, pressure and chemical conditions are favorable. However, discoveries made within the past few decades have greatly expanded our view of the range of conditions capable of supporting life on our own planet; *e.g.*, microbial life forms that survive, and even thrive, at high and low extremes of temperature and in extremes of acidity, salinity, alkalinity and concentrations of heavy metals that were once considered lethal. These discoveries on Earth, coupled with a fuller understanding of the range of possible conditions on other planetary bodies, have significantly expanded our view of the number of environments within our solar system that might be, or might have been, conducive to life. Based on this recent and ongoing research into the characteristics of a habitable zone, we will identify habitable zones in our solar system.

Research suggests that when the Earth formed, the inner solar nebula was too hot to retain the large quantities of water and organic materials seen in the current Earth environment. Instead, organics, water, and other volatile materials probably condensed in the outer reaches of the solar nebula, where low temperatures favored their retention in

comets. Subsequently, comet impacts may have delivered these essential ingredients to the forming inner planets. We expect to find that the planetary system we know today is strongly linked to these early mechanisms for transportation of volatiles and organics. To achieve this objective, we will focus on an inventory of the nature, history and distribution of organics and volatiles in the solar system.

NASA is developing plans for an ambitious mission to orbit three planet-sized moons of Jupiter -- Callisto, Ganymede and Europa -- which may harbor vast oceans beneath their icy surfaces. NASA's Galileo spacecraft found evidence for these subsurface oceans, a finding that ranks among the major scientific discoveries of the Space Age. The mission,

The *Jupiter Icy Moons Orbiter* enables three important science activities:

1. Scout the potential for sustaining life on these moons. This would include determining whether the moons do indeed have subsurface oceans; mapping where organic compounds and other chemicals of biological interest lie on the surface; and determining the thicknesses of ice layers, with emphasis on locating potential future landing sites.
2. Investigate the origin and evolution of these moons. This would include determining their interior structures, surface features and surface compositions in order to interpret their evolutionary histories (geology, geochemistry, geophysics) and how this illuminated the understanding of the origin and evolution of the Earth.
3. Determine the radiation environments around these moons and the rates at which the moons are weathered by material hitting their surfaces. Callisto, Ganymede and Europa all orbit within the powerful magnetic environment that surrounds Jupiter. They display varying effects from the natural radiation, charged particles and dust within this environment. Understanding this environment has implications for understanding whether life could have arisen on these distant moons.

The *JIMO* mission also will raise NASA's capability for space exploration to a revolutionary new level by pioneering the use of electric propulsion powered by a nuclear fission reactor. This technology not only makes it possible to consider a realistic mission for orbiting three of the moons of Jupiter, one after the other, it also would open the rest of the outer Solar System to detailed exploration in later missions.

called the *Jupiter Icy Moons Orbiter (JIMO)*, would orbit each of these moons for extensive investigations of their makeup, their history and their potential for sustaining life.

The Huygens probe, a cooperative project with the European Space Agency now *en route* to Saturn aboard NASA's Cassini spacecraft, will characterize the murky and mysterious atmosphere of Saturn's moon Titan. The products and pathways of long-term organic evolution on Titan have important parallels to the origin of life on Earth.

Finally, a potential New Frontiers comet surface sample return mission would bring back a sample of organic material from the surface of a comet for detailed analysis.

Objective: Understand how life begins and evolves.

To understand how life can begin on a habitable planet, it is essential to know which organic compounds are available and how they interact with the planetary environment. Geochemical synthesis is a potentially important source of organic compound and remains an important focus of research on this question. Laboratory simulations have recently demonstrated that relevant molecules can be synthesized in interstellar ices in a nascent solar system. Analyses of meteorites, interplanetary dust particles, and comets have shown that many chemical compounds essential to life processes are present in these bodies, supporting the hypothesis that these materials were delivered to Earth by comet and asteroid impacts. It is important to establish the sources of pre-biotic organic compounds and to understand their history in terms of processes that would take place on any newly formed planet. In addition, we will study Earth's geological and biological records to determine the historical relationship between Earth and its biosphere.

1 NASA currently supports research in these areas via its Astrobiology Institute and other
 2 grants in the Astrobiology Program, such as Exobiology/Evolutionary Biology Research
 3 and Analysis programs.

4 Objective: Catalog and understand potential hazards to Earth.

5 The effects of cosmic impacts on Earth were realized in the early 1980s, when the
 6 extinction of the dinosaurs was first associated with the impact of an asteroid at least ten
 7 kilometers in diameter. More recently, it has been estimated that impacts by asteroids as
 8 small as one kilometer in diameter could cause major climate perturbations and regional
 9 devastation. Furthermore, the direct effects of impacts by bodies as small as 100 meters
 10 could cause major damage on more-local scales. In 1908, the impact of a body about that
 11 size leveled 2000 square kilometers of forest near the Tunguska River, in Siberia. A
 12 similar impact on a modern city would take an enormous toll in lives and destruction. To
 13 meet this objective, we plan to determine the inventory and dynamics of bodies that could
 14 pose an impact hazard to Earth. In addition, we will determine the physical characteristics
 15 of comets and asteroids relevant to any threat they may pose to Earth.

16 *Dawn*, a Discovery mission about to enter implementation, will conduct extensive
 17 geochemical and geophysical investigations of the Main-Belt asteroids Ceres and Vesta.
 18 Vesta has been identified as the source of the basaltic achondrite class of meteorites that
 19 impact Earth. The overwhelming majority of NEOs come from the Main Belt, so
 20 physical characterization of Ceres and Vesta is important for understanding the type of
 21 threat that NEOs pose.

22 NASA's Near Earth Object (NEO) Observation program supports several teams of
 23 ground-based astronomers working toward a Congressionally mandated goal to discover
 24 at least 90 percent of the NEOs (asteroids and comets whose orbits closely approach the
 25 Earth) larger than 1 kilometer in diameter by 2008, and to determine their orbits with
 26 sufficient accuracy to predict whether any of them pose a threat to Earth. Researchers are
 27 on course to meet this goal, and, so far, none of the objects studied has been found to
 28 pose a foreseeable threat to Earth. The program is studying the feasibility and cost of
 29 extending the NEO search to much smaller, more numerous, and fainter objects capable
 30 of causing regional destruction.

31 Unique Technology Requirements for Solar System Exploration

32 Solar system exploration is a uniquely challenging endeavor. It requires us to send
 33 robotic vehicles across vast distances; furnish them with electrical power for propulsion,
 34 data acquisition and communication; place them in orbit around (or onto the surfaces of)
 35 bodies about which we may know relatively little; ensure that they survive and function
 36 in hostile environments; acquire and transmit data from these throughout their lifetimes;
 37 and sometimes bring the vehicles themselves safely back to Earth with samples.

38 The future Solar System Exploration missions described in this Strategic Plan will
 39 demand progress in power and propulsion systems, telecommunications,
 40 entry/descent/landing, mobility, autonomy, and science instrumentation. For example, the
 41 Project Prometheus is a response to the demand for high-performance, long-lived power
 42 supplies for extended missions that will carry advanced science instrumentation, high-
 43 power communications capabilities, and advanced electric propulsion. Increasingly,

1 future missions will also demand spacecraft systems that are tolerant of severe
2 environments.
3

Mars Exploration and the Public (Sample E/PO Facing Page)

The fleet of robotic spacecraft that will explore Mars over the coming decades offers a unique opportunity to engage students directly in the process of discovery.

Orbiting survey spacecraft such as the Mars Global Surveyor, 2001 Mars Odyssey, and the Mars Reconnaissance Orbiter map the entire planet's surface at a variety of wavelengths and at ever-increasing detail. A pilot project is underway to involve middle-school, high-school, and undergraduate student teams directly in acquiring and analyzing images of specific areas on Mars with the Odyssey spacecraft. In addition, teacher guides and curriculum supplements that use real data from current and past Mars missions are available.

[IMAGE: get a compelling Mars Student Imaging Program picture from Sheri Klug at Arizona State (sklug@asu.edu, 480-727-6495). Also VET THIS WRITE-UP WITH HER.]

When the Mars Reconnaissance Orbiter begins to return thousands of images from Mars at resolutions better than one meter, the opportunity arises to offer classrooms of students their own square mile of Mars to analyze. The large quantity of images expected means that, in many cases, students could have access to images that no professional scientist has ever analyzed. Thus, the tantalizing possibility of students making real discoveries exists for the first time.

[IMAGE: Get something showing MRO and demonstrating the expected quality and resolution of its images]

<http://mars.jpl.nasa.gov/classroom/>

4.2.2 Mars Exploration Program

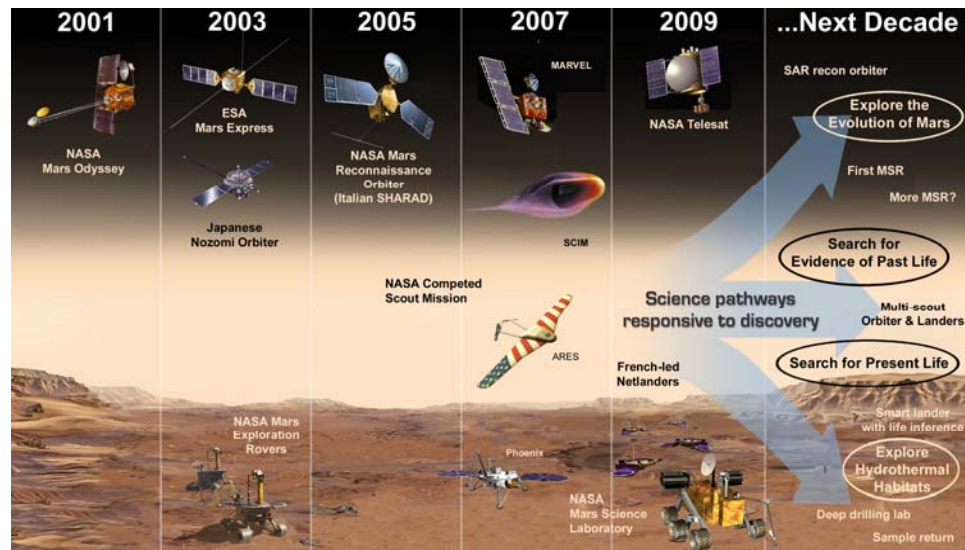
Mars holds a special place in the Solar System by virtue of its similarities to Earth, its potential for having been an abode for life, and its value as a "natural laboratory" for understanding silicate planets and the interacting systems that are germane to the environmental and geological evolution of any planet. The flood of new discoveries about Mars, including those that pertain to the role and abundance of water, the character of global climate variability, and the tantalizing array of environmental niches that exist even today as potentially life-hospitable places, has inspired a comprehensive, scientific campaign to understand the Red Planet. The overarching objectives focus on characterizing Mars, understanding its evolution and biological potential and ultimately laying the groundwork for a time in the future when human exploration will extend our current campaign of robotic scientific exploration. By understanding the biological potential of Mars, a "habitable world," we can apply this knowledge to other high-priority Solar System objects.

Objective:
Understand
the current
state and
evolution of
the
atmosphere,
surface, and
interior of
Mars.

Understanding
 Mars'
 atmosphere,

surface, and interior, and their interactions with one another can tell us much about the environment in which life could have developed there and may subsequently have been preserved. Characterizing this unique interplay of systems—atmosphere, surface, and interior—on Mars also bears directly on the search for evidence of life elsewhere in the Universe.

NASA is planning a methodical succession of orbiting and surface laboratories over the next decade to progressively refine our understanding of the planet. In the near term, the Mars Global Surveyor orbiter will continue to characterize the dust and temperature properties of the martian atmosphere, document surface landforms that show evidence of liquid water erosion and climate change, and refine our knowledge of the interior by mapping Mars's magnetic field and gravity. Currently, the 2001 Mars Odyssey orbiter is mapping the bulk elemental composition and mineralogy of the martian surface, as well as documenting aspects of the water cycle on Mars. The two 2003 Mars Exploration Rovers will make *in situ* observations of the chemistry, mineralogy, and bulk mechanical properties of the surface materials on Mars at two locations where liquid water appears to have played a major role. Also to be launched in 2003, the NASA subsurface sounding



1 radar on the European Space Agency (ESA) Mars Express orbiter will map the
2 uppermost 1-5 km of the martian crust in search of water-related layering and other
3 fundamental subsurface structures.

4 Later in the decade, the 2005 Mars Reconnaissance Orbiter will characterize atmospheric
5 processes over a full Mars year and provide the first measurements of local mineralogy
6 relevant to the role of liquid water on the surface. This orbiter will also document
7 layering on the surface to clarify how the surface has evolved in association with standing
8 bodies of water or other water-related processes. In 2007, a Mars Scout mission will
9 augment the core program with a competitively selected investigation that will fill known
10 and emerging measurement gaps related to the "habitability of Mars." Subsequently, the
11 2009 Mars Science Laboratory will explore a compelling local site on Mars's surface for
12 evidence of organic materials and other diagnostic signatures of past or present life,
13 including microscopic textures and associated chemistry. Additional missions for the
14 2011 and 2013 launch opportunities will be selected on the basis of new knowledge about
15 Mars obtained during current and planned future investigations.

16 Objective: Determine if life exists or has ever existed on Mars.

17 The search for life, past or present, on Mars entails the study of meteoritic material from
18 Mars as well as exploration of Mars itself for biomarkers and other indicators of
19 biological processes. NASA sponsors studies of Mars meteorites to detect the presence of
20 chemical indicators of life or, at least, life-hospitable indicators such as water. In
21 addition, NASA sponsors development of new sensors that will be able to search for
22 evidence of organic materials *in situ* on Mars. Understanding the context for life at
23 anytime or place on Mars is central to this activity. There may be present-day
24 environmental niches on Mars that are life hospitable, as well as specific deposits that
25 have favored preservation of organic materials. Chemical indicators of prebiotic activity
26 are also connected to the question of whether life ever arose on Mars.

27 Orbital reconnaissance by the Mars Global Surveyor, Odyssey, and the Mars
28 Reconnaissance Orbiter will enable us to focus landed missions on the highest priority
29 surface sites relevant to the search for life on the basis of evidence for past or present
30 water or by locating telltale minerals indicative of hospitable ancient environments. The
31 Mars Exploration Rovers and Mars Science Laboratory will land on Mars and explore
32 three sites for mineralogical and chemical evidence of the role of water. The Mars
33 Science Laboratory will seek organic materials or related biosignatures in the accessible
34 surface layer. The 2007 Mars Scout mission will also contribute to the understanding of
35 the habitability of Mars from alternate vantage points and unique experimental
36 perspectives to complement other Mars missions.

37 Objective: Develop an understanding of Mars in support of possible future human
38 exploration.

39 Focused measurements of the martian environment will help us identify potential hazards
40 to human explorers and will allow us to inventory martian resources of potential benefit
41 to future human missions. Missions over the next decade will characterize the distribution
42 of water—as ice or liquid—both from orbit and from *in situ* analysis of local materials, as
43 well as provide understanding of the space radiation environment in the vicinity of Mars.

The Mars Global Surveyor and Odyssey orbiters have already improved estimates of the abundance of water within the uppermost surface layer, atmosphere, and icecaps of Mars. The 2005 Mars Reconnaissance Orbiter mission will use radar to search as deep as hundreds of meters for evidence of water-bearing layers. *In situ* measurements of the martian environment, mechanical properties, toxicity of local materials, and composition of specific materials will be conducted by the 2003 Mars Exploration Rovers and later by the 2009 Mars Science Laboratory, which will emphasize characterization of organic and related molecules. The Odyssey orbiter is presently measuring the galactic cosmic radiation background from Mars orbit, and it is likely that measurements of solar and cosmic radiation will be conducted from the Mars surface later in the present decade. The 2009 Science Laboratory mission will access the shallow subsurface to measure the presence of water and oxidants as a function of depth. Thus, by early in the next decade, a relatively complete inventory of critical environmental parameters, local hazards, and potential resources will be available to support future human exploration.

Unique Mars Exploration Technology Requirements

Comprehensive scientific exploration of Mars during the current decade and projected into the next requires unique technology investments and developments. Given the technology maturity required to make substantial headway in the understanding of the habitability of Mars, near-term investment in the following capabilities is needed:

- Precision, targeted access to the surface of Mars via improved Entry, Descent, and Landing systems (i.e., better than 10-km horizontal precision)
- Access to the shallow subsurface of Mars to depths in excess of 1 meter
- Enhanced lateral mobility systems that allow access to a greater breadth of materials for *in situ* analysis
- Longer-lived surface power systems that provide for year-long surface operations at virtually all latitudes, independent of solar illumination
- Improved *in situ* analytical instruments for precise measurements of key chemical indicators, presence of liquid water, and geophysical parameters
- *In situ* sample acquisition, preparation, distribution, and handling necessary for definitive surface-based analyses of a full range of materials (rock, soil, dust, ices, gases, etc.)
- Ascent vehicle systems suitable for launch of carefully selected martian samples to Mars orbit
- Airborne platforms suitable for obtaining regional to local scale observations not possible from surface-based vehicles
- Penetrator systems with high-g tolerant measurement systems that provide access to complex, high-priority terrains
- Systems necessary for containment and potentially caching of samples for eventual return to Earth

- 1 • New classes of instruments that can operate below the ground or ice surface of
2 Mars for direct observations of unique materials and environmental conditions
- 3 • Small, surface scientific stations suitable for developing a global planetary
4 network for understanding the climate and interior of Mars
- 5 • Active landing-hazard avoidance systems to facilitate precision landing even in
6 more complex terrains
- 7 • Automated orbital rendezvous systems needed for future Mars sample return
8 missions

9 These capabilities and the technologies associated with them are directly linked to
10 planned and potential missions that will advance our knowledge of Mars as a system, as
11 we explore the planet for evidence of its biological potential. In addition, the Mars
12 Exploration Program will serve as a technology pathfinder for exploration of other Solar
13 System bodies. For example the 2009 Mars Science Laboratory requires unique
14 capabilities for *in situ* sample acquisition, handling, and preparation. These capabilities
15 are vital to its mission as our next-generation landed laboratory, but will also serve other
16 high-priority Solar System Exploration mission needs.
17

Sun-Earth Connection and the Public (Sample E/PO Facing Page)

The Sun-Earth Connection theme investigates phenomena that directly impact people's lives but are not often in people's conscious thoughts. SEC will use high-visibility events, such as the 2004 transit of Venus across the face of the Sun or the 2006 total eclipse of the Sun, to draw national attention and provide opportunities to educate the public about the Sun and its impacts on Earth. Associated activity guides for teachers will bring such events into classrooms across the county.



*Live broadcast/Web cast of the 2001 solar eclipse from Africa
(get high resolution from Larry.Cooper@hq.nasa.gov or Isabel Hawkins
isabelh@ssl.berkeley.edu)*

The Sun-Earth Connection will increase the impact on classroom education by developing curriculum materials connecting the National Education Standards and the following SEC E/PO Themes:

- Solar Variability. Solar variability disrupts technological systems and influences climate and the debate on global warming.
- Voyage to a Star. The Sun is only star a NASA mission will visit in the foreseeable future and the physical environment near the Sun is extreme.
- Magnetic Fields. These prime examples of action-at-a-distance are inherently fascinating to your people and appear prominently in national science education standards.
- Voyage to the Unknown. The continuing trek of the Voyager and Pioneer spacecraft to the edges of the solar system and beyond continues to fascinate students and the public.

4.2.3 Sun-Earth Connection

Life on Earth prospers in a biosphere sustained by energy from the Sun. Though our planet orbits within the inhospitable outer layers of the atmosphere of a magnetically variable star, Earth's atmosphere and magnetic field shield the surface from the dangerous radiation and particles coming from the Sun and the galaxy beyond. The region of space influenced by the Sun, called the heliosphere, extends beyond the planets and ultimately ends where the solar wind impacts the interstellar medium. Studying the local interstellar medium may reveal its galactic origins and show, more generally, how the interstellar medium can influence a stellar system.

The Sun provides the most accessible example for understanding the structure and evolution of stars and stellar systems. Knowledge of long-term variability of solar activity is important because of its effects on planetary atmospheres, the radiation and energetic particle environment, planetary surfaces, and therefore the development of life. The elements of this stellar-planetary system are highly interlinked. Continued progress will require theory, modeling, and data analysis that cross traditional discipline boundaries.

The aim of the Sun-Earth Connection (SEC) Theme is to understand the Sun, heliosphere, and planetary environments as a single connected system.

Objective: Understand the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments.

At one end of the causal chain lie questions about the structure and dynamics of the Sun, its corona and solar wind, and the origins of solar magnetic variability. At the opposite end of the chain, we need to determine how the variable heliosphere interacts with the interstellar medium at its outer boundary at the edge of the Solar System, the heliopause. Between Sun and heliopause orbit the planets. Understanding how their unique magnetospheres and atmospheres respond to both internal and external drivers will help explain the behavior of our own planet. This broadest Theme Objective includes research focus areas appropriate to both STP and LWS missions.

Sun-Earth Connection Missions

Most Sun-Earth Connection Theme strategic missions are in the Solar Terrestrial Probes (STP) or Living With a Star (LWS) Program lines. These lines of moderate-cost strategic missions provide regular flight opportunities.

Each STP mission addresses a fundamental science question about the fundamental physics of plasmas and the flow of mass and energy in the solar system, Objectives 1 and 2 below.

The LWS missions are coordinated to develop knowledge and understanding of aspects of the connected Sun-Earth system that directly affect life and society; LWS missions are associated primarily with Objectives 1 and 3.

Three other flight programs can supplement the present lines: competitive opportunities for sharply focused investigations in the Enterprise's Explorer program; potential collaborative missions with other agencies and divisions, such as the European Space Agency's *Solar Orbiter* or the Solar System Exploration Theme's *Jupiter Polar Orbiter* and more ambitious and challenging missions, such as *Solar Probe*, that do not fit within the mission lines and require new resources.

Two relevant STP missions are already in development. *Solar-B*, a Japanese mission with significant NASA participation, will reveal how the photosphere is magnetically coupled to the corona and will track the life cycle of small magnetic regions at the solar surface with high resolution solar telescopes. *STEREO* will determine how coronal mass ejections begin and how they propagate to the orbit of the Earth; *STEREO*'s two spacecraft in solar orbit move gradually ahead and behind the Earth to provide the first stereoscopic views of evolving features in the solar atmosphere.

The Sun-Earth Connection Theme plans two related missions in the near term. *Geospace Electrodynamics Connections (GEC)* is an STP mission to investigate how the Earth's ionosphere-thermosphere system responds to the variations in the overlying magnetosphere; it features four spacecraft in very low-perigee orbits measuring *in situ* conditions.

If resources become available, the *Solar Probe* will plunge to within two million miles of the solar surface to determine the origins of fast and slow solar wind. This first voyage to a star poses special technological challenges because of the extreme and unknown environment.

Later STP mission concepts include: a constellation of 50 or more nanosatellites in the Earth's magnetotail to understand the regulation of the magnetosphere; a probe to measure the polar regions of the Sun and the heliosphere from high solar latitude; a two-spacecraft mission to determine how small-scale waves in the Earth's upper atmosphere couple to its lower atmosphere; and a deep space probe to remotely image the boundaries of the heliosphere by detecting interstellar neutral atoms and radiation.

Objective: Understand the fundamental physical processes of space plasma systems.

This Objective spans many astrophysical problems and relies primarily on STP missions. One focus is to discover how solar magnetic fields are created and evolve and how they produce high-energy particles. Mechanisms for creating, destroying, and reconnecting magnetic fields are key to many Sun-Earth Connection problems – solar activity, geomagnetic activity, the heliospheric boundary, and most forms of particle acceleration. The other space plasma research focus area involves understanding how and why processes that occur on very small scales generally affect large-scale global dynamics. This coupling across multiple scale lengths is important for understanding instabilities and turbulence. The solar system offers the opportunity to test the scientific understanding of these processes in diverse plasma environments.

In the near term the Magnetospheric MultiScale STP mission will measure turbulence, reconnection, and particle acceleration at small and intermediate scales using a small cluster of spacecraft to explore key magnetosphere locations. Potential collaboration on ESA's *Bepi-Colombo* mission to Mercury may show how a planetary magnetosphere interacts with the solar wind in the absence of an ionosphere.

A later STP mission in this area may focus on reconnection and micro-scale processes in the solar atmosphere using both high-resolution spectroscopy and imaging. Another, perhaps developed jointly with the Solar System Exploration Theme, would produce imaging and *in situ* data of the auroral regions of Jupiter to compare its magnetosphere with those of the Earth.

Objective: Understand the origins and societal impacts of variability in the Sun-Earth connection.

This objective has the most practical impact on society and relies primarily on LWS missions. Two areas concern relatively short time-scale space weather. The first relates to disturbances that travel from Sun to Earth; this requires development of the capability to forecast solar activity and predict the evolution of structures as they propagate through the heliosphere. The second involves even shorter time scales where a need exists to first specify and ultimately enable prediction of changes to the Earth's radiation environment, ionosphere, and upper atmosphere. On longer time scales, human society has a real need to understand the role of solar variability in driving global change in Earth's atmosphere and space climate.

In the near term plan, the LWS *Solar Dynamics Observatory* (SDO) will observe the solar interior and atmosphere continuously from geosynchronous orbit to determine the causes of the solar variability that affects Earth. Coordinated observations from the two LWS Geospace Storm Probes will link the solar and geospace systems. The *Ionospheric-Thermospheric Storm Probes* will determine the causes of ionospheric variability and irregularities at middle latitudes that affect communications. The *Radiation Belt Storm Probes* will determine how the radiation belt particles that affect astronauts and spacecraft performance are injected, accelerated, distributed, and eventually lost.

Subsequent LWS mission candidates include sentinels in the inner heliosphere to measure how changing conditions inside the Earth's orbit affect propagation of solar emissions directed toward Earth, a constellation of small spacecraft in the inner magnetosphere to identify how the coupling between the Earth's radiation belts, ring current and plasmasphere produces energetic particles, a mission to discover how the low-latitude coupling of the mesosphere, thermosphere, ionosphere, and plasmasphere affects communications; and a high-resolution investigation of the global dynamics of the solar transition region that controls the stability of larger-scale structures.

Unique Sun-Earth Connection Technology Requirements

Advances in many technologies, such as power and communication systems, avionics, navigation, and materials, will enable or enhance future missions. However, progress in four key areas is vital for SEC's planned mid- and long-term missions.

- 1) Spacecraft systems for affordable clusters and constellations of small, ultra-low-power satellites;
- 2) Information technology that will allow convenient access to an unprecedented volume of data from multiple spacecraft in diverse locations to researchers in various fields and improve spacecraft autonomy to reduce spacecraft operations costs;
- 3) Larger, faster, and more capable scientific detectors, as well as lightweight precision optics and filters for remote sensing instruments; and
- 4) Solar sails or other advanced propulsion systems that allow spacecraft to reach or remain in crucial but difficult vantage points, such as the Sun's poles, the interstellar medium, or hovering upstream in the solar wind or above the Earth's poles.

Astronomical Search for Origins and the Public (Sample E/PO Facing Page)

The Origins theme seeks to answer questions that have endured since humans first looked into the night sky from campfires. Origins missions, such as the Hubble Space Telescope, have not only opened the public's eyes to a vast range of cosmic phenomena, they have also provided compelling images of creation in action.

The Cone Nebula, captured by the HST Advanced Camera for Surveys, is a site of current star formation.

Through means such as the HubbleSite and the publication of *Touch the Universe: A NASA Braille Book of Astronomy*, we have made the images and stories of our origins available to a broad cross-section of the public and have provided materials for students and teachers.

Future Origins missions will provide even greater opportunities to educate and to engage the public in this journey of discovery. For example, the Space Infrared Telescope Facility will introduce audiences to the invisible infrared Universe where stars and



complicated molecules are born. The Navigator missions, Space Interferometry Mission and Terrestrial Planet Finder, will take the public and educational community along on the quest to find Earth-like planets orbiting stars other than our Sun. The Astrobiology program will reveal new understandings of the origins of life and its tenacity to survive in extreme environments.

4.2.4 *Astronomical Search for Origins*

The Origins theme focuses on two questions: “Where did we come from?” and “Are we Alone?” While these questions are simple, the scientific and technical challenges to answer them are complex. Today the Universe is full of structure, from giant but simple galaxy to minuscule, but complex single living cells. Our objective is to understand how this astronomical structure came about, how stars and planets form, how the chemical elements are made, and ultimately how life originates.

Objective: Understand how today’s universe of galaxies, stars and planets came to be

Research on this objective aims to determine how the cosmic web of matter that emerged from the Big Bang organized into the first stars and galaxies, how different galactic ecosystems of stars and gas form, and which of these ecosystems can lead to planets and living organisms.

Stars began to form even before the first galaxies, and what had been a calm, near formless sea began to surge with the froth of complex forms of matter and energetic processes. There is growing evidence that star formation began before there were galaxies, and that when these early stars died explosively as supernovae they produced the first spray of heavy elements. But it also appears that the birth of galaxies, by binding the stars and gas together to create these cosmic ecosystems, was crucial to the buildup of these heavy elements to a level where planets and life were possible. The emergence of such enormous structures from the formless universe that preceded them and the manufacture of vast amounts of heavy elements by stars were key steps on the road to life.

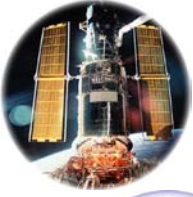
We intend to investigate how the diversity of galaxies in today's universe emerged from the assembly of the first galaxies and the subsequent evolution of their stars. Finally, we will show how the life cycle of stars led to the chemical elements needed for planets and life and determine if there is a region in our galaxy which is especially suited to the development of life: a galactic habitable zone.

Through technology, astronomers can “travel back through time” to witness these crucial steps in our origins. Both present and planned facilities—the Hubble Space Telescope (HST), the James Webb Space Telescope (JWST), the Space Infrared Telescope Facility (SIRTF), and the Stratospheric Observatory for Infrared Astronomy (SOFIA)—will be used to study the formation of the earliest stars and heavy elements and to study how the formation of early black holes influenced the structure of the early Universe.

Direct detection of the first generation of stars will almost certainly require the unprecedented sensitivity of the Webb telescope to be launched at the end of the decade. Observations of high redshift star formation and active galactic nuclei by the Hubble and Webb telescopes will allow us to trace the buildup of galaxies with time. Observations by SIRTF and the Webb Telescope will be crucial for tracing the energy budget of galaxy formation and early evolution. SIRTF will also characterize the large-scale infrared properties of 75 nearby galaxies to correlate star formation rates with properties of the interstellar medium.

1 Origins Missions Box:

2



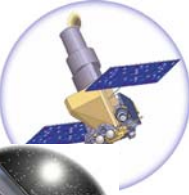
Operating Missions

Hubble Space Telescope – 2.5-meter telescope in low Earth orbit collecting images and spectra in the visible and neighboring bands studying the early phases of the modern universe.

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Far Ultraviolet Spectroscopic Explorer – space telescope in low Earth orbit working in the far ultraviolet band exploring the hydrogen isotope ratio created in the big bang and the chemical composition of galaxies.

Space Infrared Telescope Facility – 0.85-meter cryogenic telescope in solar orbit, aimed at understanding structure and composition of molecular clouds and the early stages of star and planet formation.

Future Missions

Stratospheric Observatory for Infrared Astronomy – 2.5-meter telescope flying on a modified Boeing 747 collecting data on the properties of the clouds of gas and dust that lie between stars in a galaxy.

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Kepler – photometric survey telescope in space, selected in the Discovery program, to survey the extended solar neighborhood to detect and characterize planets down to Earth size.

Space Interferometry Mission – 10-meter baseline optical interferometer in solar orbit looking for evidence of Earth-size planets around nearby stars.

James Webb Space Telescope – infrared telescope, at least 6-meter diameter, in solar orbit aimed at exploring the earliest galaxies.

Terrestrial Planet Finder – infrared interferometer or visible-light coronagraph, to directly detect and characterize potential atmospheres of planets like Earth.

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1 Objective: Learn how stars and planetary systems form and evolve

2 This objective will focus on tracing the path of gas and dust to stars and planets, detecting
3 planetary systems around other stars, and understanding planetary systems' architectures
4 and evolution.

5 During the past three decades, we have used both ground and space based facilities to
6 look inside the nurseries where stars and planets are born. Parallel studies of the solar
7 system, conducted with planetary probes, and of meteorites have revealed clues to the
8 processes that shaped the early evolution of our own planetary system. An overarching
9 goal of science in the 21st century will be to connect what we observe elsewhere in the
10 universe with objects and phenomena in our own solar system.

11 Astronomers have now identified the basic stages of star formation. The process begins in
12 the dense cores of cold gas clouds (molecular clouds) that are on the verge of
13 gravitational collapse. It continues with the formation of protostars, infant stellar objects
14 with gas-rich dusty circumstellar disks that evolve into adolescent "main-sequence" stars.
15 Tenuous disks of ice and dust that remain after most of the disk gas has dispersed
16 surround these more-mature stars. It is in the context of these last stages of star formation
17 that planets are born.

18 In pursuing this objective, we will investigate how molecular clouds act as the cradles of
19 star and planet formation. We will determine how proto-planetary dust and gas disks
20 mature into planetary systems, and search for evidence of planets in the disks around
21 young stars. We will conduct a census of planetary systems around stars of all ages.

22 First SOFIA and SIRTf, and later a large-aperture spaceborne telescope, will be able to
23 determine the temperature, density and velocity structure of molecular clouds. The Webb
24 Telescope will be able to probe the most central regions of protostars. High angular-
25 resolution studies in the near-infrared conducted using the Webb Telescope and SIRTf
26 and far-infrared using SIRTf and SOFIA are necessary to trace the distribution of
27 important planetary constituents such as water, ice, silicates, and complex carbon
28 molecules in the disks around young stars. SIRTf will give us our first hints about gas
29 and dust dispersal, but large telescopes such as the James Webb Space Telescope are
30 ideally suited to track the evolution and map the structure of vestigial debris disks around
31 nearby main-sequence stars.

32 The Terrestrial Planet Finder will be essential to separate planetary radiation from that of
33 the surrounding disk and the star and to possibly enable us to directly image young
34 protoplanets.

35 Objective: Understand the diversity of other worlds and to search for those that might
36 harbor life

37 Toward the ultimate goal of finding life beyond our solar system, the Theme asks what
38 are the properties of giant planets orbiting other stars, how common are terrestrial
39 planets, what are their properties, which of them might be habitable, and is there life on
40 planets outside the solar system?

41 After centuries of speculation, we finally know that there are indeed planets orbiting
42 other stars. The extrasolar planets discovered so far seem to be gas giants like Jupiter.

Earth-like worlds may also orbit other stars, but until now our measurements lack the precision needed to detect a world as small as the Earth. However, detection of Earth-sized planets could happen before the end of the decade through a Discovery mission, Kepler. Even before then, detailed studies of giant planets will tell us much about the formation and history of planetary systems, including our own. We have already made a first reconnaissance of the atmospheric properties of one such giant planet that passes directly in front of its star and allows us to probe its atmosphere even if we can't see the planet directly.

The *Kepler* mission, surveying a myriad of distant stars, will be our first opportunity to find out how common it is for a star to have an orbiting Earth-like planet. We will also learn how big these planets are and where they are located in relation to their stars' "habitable zones" where life as we know it is possible.

The flagship mission to carry forward the search for Earth-like worlds will be the *Terrestrial Planet Finder*, which will image nearby planetary systems and separate the extremely faint light of a terrestrial planet from its parent star.

Once we have found terrestrial planets orbiting nearby stars, we can then tackle two even more ambitious objectives: to determine which of these planets actually have conditions suitable for life and which, if any, actually show signs of past or present life. Studies are underway to learn which "bio-signatures"—identifiable spectral feature in a planet's light—can reveal past or present life on a planet, and to plan future telescopes capable of making such observations.

Unique Astronomical Search for Origins Technology Requirements

The Origins technology plan has two strategic objectives. In the near term, the maturing technologies for observatories like the Space Interferometry Mission, the James Webb Space Telescope, and the Terrestrial Planet Finder must be completed and tested. These technologies include precision metrology and microdynamic disturbance reduction; rapid lightweight mirror panel fabrication and folded mirror deployment and alignment; and coronagraphic and advanced interferometric techniques.

For the longer term, it is critical to begin establishing the new technological building blocks for very large space observatories to follow. These observatories will require advances in four key areas: large lightweight mirrors for all wavelengths, active systems for precise control of optical elements, new detectors to improve the efficiency of collecting radiation, and cooling technologies to minimize the infrared radiation from warm telescopes.

Structure and Evolution of the Universe and the Public (Sample E/PO Facing Page)

How did the Universe begin? Why is it growing, and what is its ultimate fate? What is the nature of space and time? Is there a beginning to time? Does space have edges? How did the Universe evolve over the eons from an initially amorphous gas of high energy radiations to its present state, in which stars and galaxies act as oases for the formation of intelligent life? These fundamental questions form the basis of the Structure and Evolution of the Universe (SEU) theme's research program and also serve as entry points for engaging the public and the educational community in scientific inquiry.

Cosmic Questions: Our Place in Space and Time is a 5,000-square-foot traveling museum exhibition that invites visitors to explore the fundamental questions and gain an understanding of recent discoveries about the origin, evolution, and structure of the universe. Much of *Cosmic Questions*' success can be attributed to the collaborations that helped build it. Nine NASA space science missions, 14 major science institutions or universities, and dozens of space scientists contributed their scientific expertise as well as data, images, and artifacts from their missions. The NASA Structure and Evolution of the Universe Education Forum and the Boston Museum of Science provided coordination and expertise in exhibition development. Such collaborations are a hallmark of the NASA Space Science E/PO program. During its 2002 opening run at the Boston Museum of Science, *Cosmic Questions* had more than 350,000 visitors. Another 3 million visitors are anticipated in the 10 cities that *Cosmic Questions* will visit through 2005.

Our home, the Milky Way galaxy, serves as Cosmic Question's gateway to exploring fundamental questions and recent discoveries about the origin, evolution, and structure of the universe.

Visitors go beyond the visible and see what the Universe looks like through the eyes of the Chandra X-ray Observatory.

The universal appeal of these cosmic questions also offers an opportunity to bring the excitement of cosmic exploration into the nation's classrooms. Exploring the size and shape of the Universe, examining evidence for the Big Bang, and most importantly, tracing the underlying idea that scientific inquiry can address even the most ancient and difficult questions, are key topics in the *National Science Education Standards*. As future missions weave the ongoing story of cosmic evolution, accompanying educational efforts share that story with teachers through professional development opportunities and curriculum enhancement materials tied to the National standards. In this manner, this NASA Theme will soon provide the *majority* of materials on these subjects in our nation's schools.

4.2.5 Structure and Evolution of the Universe

This Theme is dedicated to answering the most fundamental questions that one can ask about our Universe: How did the Universe begin? Why is it growing, and what is its ultimate fate? What is the nature of space and time? Is there a beginning to time? Does space have edges? How did the Universe evolve over the eons from its initially formless state to the present, in which stars and galaxies act as oases for the formation of intelligent life? These are the highest priority questions of the SEU theme and are addressed in the new *Beyond Einstein* program (see box).

The Universe we see today is a very dynamic one: Stars are born, and stars die, either with the explosive demise of a supernova, or the lingering, cold death of a white dwarf. Galaxies evolve, collide, and become transiently bright beacons seen across the entire universe. The patterns of exchange of matter and energy in these processes dictate how our Universe appears to us today, and helps explain how life had the opportunity to come into being. These questions form the basis for the *Cycles of Matter and Energy* program, the second of this Theme's two science programs.

The SEU theme seeks to explore and understand, at the most fundamental level, the dynamic transformations of energy in the Universe, from the beginning to time to the present day and beyond, to study the entire web of interactions that determine the evolution of our cosmic habitat.

Objective: Discover what powered the Big Bang and the nature of the mysterious dark energy that is pulling the Universe apart.

Einstein's General Theory of Relativity predicted the expansion of the Universe. However, we must go beyond Einstein's theory to uncover the motive force that helped power the Big Bang and made our Universe as large as it is, allowing stars and galaxies to form and life to evolve. Einstein's theory also predicted the presence of a ubiquitous, invisible energy that causes the Universe to accelerate, but we must once again go beyond Einstein's theory to understand the origin and nature of this "dark energy."

One of the most promising new theories, that of the *inflationary universe*, explains how the Universe grew from being very small to very large ("inflation") within the first fraction of a second of its existence. This theory also predicts we can directly view this birth of the Big Bang by looking at the gravitational radiation—wavelike ripples in space-time—that was produced then and continues to propagate through the Universe now. Gravitational radiation uniquely allows us to see back to the first tiny fraction of a second in the age of the Universe. Evidence for inflation can also be found through subtle patterns in the cosmic microwave background, the universal sea of low-energy photons produced when electrons and protons first combined to form neutral hydrogen approximately 400,000 years after the Big Bang.

After its early and brief period of inflation, the Universe has continued to grow in accordance with Einstein's theory of gravity. Its growth, its shape and size, and its destiny are determined by its visible matter, dark matter, and dark energy contents. Surprisingly, we still do not know the nature of 95% of the content of the Universe. The newly discovered dark energy, whose origin is a complete mystery, dominates the evolution of the Universe.

Beyond Einstein

Einstein and his successors, in their attempts to understand how space, time, and matter are connected, made three predictions: First, space is expanding from a Big Bang; second, space and time can tie themselves into contorted knots called “black holes” where time actually comes to a halt; third, space itself contains some kind of energy that is pulling the Universe apart. These predictions seemed so fantastic that Einstein himself regarded them as unlikely, yet they have turned out to be true. But Einstein’s theory alone cannot answers such questions as (1) What powered the Big Bang? (2) What happens to space, time, and matter at the edge of a black hole? or (3) What is the actual nature of the mysterious dark energy pulling the Universe apart? For this, we need to go beyond Einstein, to explore new theories that predict unseen dimensions and entire universes beyond our own. This is the quest of the *Beyond Einstein* missions, to help usher in the next revolution in understanding our Universe with crucial investigations that can be done only in space.

The *Beyond Einstein* mission line has two *Einstein Observatories*: the *Laser Interferometer Space Antenna*, a deep-space-based gravity wave detector that will open our eyes to the as-yet unseen cosmic gravitational radiation; and the *Constellation-X* mission, which through x-rays will tell us what happens to matter at the edge of a black hole. Three *Einstein Probes* will answer, “What powered the Big Bang?” (an inflation probe), “How did black holes form and grow?” (a black hole finder probe), and “What is the mysterious energy pulling the Universe apart?” (a dark energy probe). Two *Vision Missions*: a big bang observer and a black hole imager, will explore very close to the instant of creation through gravity waves and obtain the first direct image of a black hole.

The *Beyond Einstein* missions will connect humans to the vast Universe far beyond the Solar System, to the entirety of creation. They will extend our senses beyond what we can imagine today: to the largest and smallest things, the beginnings and ends of time and space. The images and knowledge gained in this quest will inspire all humanity—as only NASA can.

1 The *Laser Interferometer Space Antenna (LISA) Einstein Observatory* will measure
 2 gravitational radiation generated by a variety of astrophysical phenomena, including
 3 merging black holes and stars falling into supermassive black holes. *LISA*, to be
 4 undertaken jointly with the European Space Agency, will also search for gravity waves
 5 created during the earliest moments of the Big Bang, that could allow us to see back
 6 nearly to time's origin.

7 The *Dark Energy Probe* will measure the amount of light emitted by thousands of
 8 cosmologically distant supernovae, thereby telling us the expansion rate of the Universe
 9 over the last several billions of years. Since dark energy has dominated the Universe's
 10 energy content during this time, we can learn from this whether dark energy is constant or
 11 varying over time. If it is constant, then dark energy is an energy that comes from the
 12 vacuum of space itself. If not, then it may show signs of a richer structure predicted by
 13 string theory, in which spacetime has more dimensions than we perceive with our senses.

14 The *Inflation Probe* will seek the imprint of primordial gravitational waves on the relic
 15 cosmic microwave background. This will test inflation theory of the very early Universe,
 16 and will also test physics at energies that are currently inaccessible by any other means.

17 The *Constellation-X Einstein Observatory* will constrain the nature of dark matter and
 18 dark energy by observing their effects on the formation of clusters of galaxies.

19 Objective: Learn what happens to space, time, and matter at the edge of a black hole.

20 The greatest extremes of gravity in the Universe today exist at the edges of black holes.
 21 Nearby matter captured by the strong gravity of a black hole falls inward, accelerating to
 22 speeds comparable to that of light. This infalling gas, including that of stars shredded by
 23 the intense gravity fields, heats up dramatically, producing large quantities of x-ray
 24 radiation which can be used as diagnostics for physical processes occurring near the
 25 surface of a black hole. By measuring such x-rays we can observe the slowing of time
 26 near the surface of a black hole and investigate how matter releases energy near its
 27 surface. We can also observe the evolution of black holes in distant galaxies and quasars,
 28 and determine their role in the evolution of their host galaxies.

29 As compact objects such as neutron stars or stellar-mass black holes fall into a
 30 supermassive black hole, they generate ripples in space-time, known as gravitational
 31 radiation. By observing the waveforms of these ripples we can map the knotted structure
 32 of space and time around a black hole, and determine if the astonishing predictions of
 33 Einstein's theory are correct: (1) the freezing of time and (2) the dragging of space
 34 around a black hole.

35 The merger of two supermassive black holes, believed to occur during collisions between
 36 galaxies, is a catastrophic event in space-time, and produces gravity waves, which are
 37 detectable throughout the entire Universe. These waves are gravitational "photographs"
 38 that document the evolution not only of the supermassive black holes themselves, but
 39 also that of their host galaxies.

40 *Constellation-X* will greatly extend our capability for high-resolution x-ray spectroscopy.
 41 Its key goals are to determine the fate of gas falling into a black hole by tracking spectral
 42 features close to the black hole's "surface" and to trace the evolution of black holes with
 43 cosmic time by obtaining detailed spectra of faint quasars at high redshift.

LISA will provide us with perhaps the first direct detection of gravitational radiation, a phenomenon predicted by Einstein’s theory of gravity. It will easily detect supermassive black hole mergers occurring throughout the Universe, and will provide us with precise maps of the deformed structure of space-time near the surface of a black hole, testing Einstein’s theory.

The *Black Hole Finder Probe*, one of the *Einstein Probes*, will perform the first all-sky imaging census of accreting black holes—ones into which stars and gas are falling—from supermassive black holes in the center of galaxies, to intermediate black holes produced by the very first stars, to stellar mass holes in our own Galaxy.

Objective: Understand the development of structure and the cycles of matter and energy in the evolving Universe.

The Universe is governed by cycles of matter and energy. Even as the Universe expands, pockets of atomic matter and dark matter collapse by the force of gravity to form galaxies and clusters of galaxies. Dense clouds of gas within galaxies collapse to form stars, in whose centers all of the elements heavier than hydrogen and helium are produced. When stars die, they eject some of these freshly produced, heavier elements into space, forming galactic clouds of gas and dust in which future generations of stars are born, beginning another cycle of matter.

The luminous energy from stars, which we see in the night sky and from our Sun, comes from the energy of thermonuclear fusion, in which the “fuel” of original hydrogen and helium gas is “burned,” leaving as “ash” the heavier elements. When a star’s fuel is consumed, its life ends. For the most massive stars, the end comes as a supernova; the stellar core collapses to a neutron star or black hole, releasing vast quantities of gravitational energy that cause the supernova to momentarily outshine its host galaxy.

This energy strongly affects the environment of nearby stars, and also is believed to be responsible for the origin of the most energetic particles in the Universe, cosmic rays. Similar processes are believed to be at work in such extraordinary phenomena as gamma ray bursts and cosmic jets.

The aim of the *Cycles of Matter and Energy* program, the second program of this Theme, is to understand these cycles and how they created the conditions for our own existence. To understand how matter and energy are exchanged between stars and the interstellar medium, we must study winds, jets, and explosive events. To understand the formation of galaxies, we need to map the “invisible” Universe of dark matter that helped nucleate these structures, observe the gas expelled during the birth of galaxies, and witness the birth of the first black holes and their effect on the formation of galaxies.

The *Gamma-ray Large Area Space Telescope* will measure gamma rays emitted by a variety of extremely energetic objects, such as quasars. A quasar is a galaxy in which large quantities of gas are falling onto a supermassive black hole that occupies the galaxy center, releasing huge amounts of gravitational energy. This energy goes into the creation of cosmic jets, which shine as sharp beacons in the gamma ray region of the electromagnetic spectrum. By measuring the spectra of these emissions, this mission will explore the details of the complex interactions that occur in these “cosmic cauldrons.”

Gravity Probe-B will be a polar-orbiting satellite that will measure two remarkable effects predicted by Einstein's General Theory of Relativity to unprecedented precision, both effects due to the distortion of space-time created by the spinning mass of our Earth. One of the effects, called "frame-dragging," in which space itself is twisted along with the rotation of a massive body, has never been directly observed before. If these effects are not observed, it would call into question the validity of Einstein's theory.

Two future Explorer missions will contribute to our understanding of the cycles of matter and energy: *Swift* and *Spectroscopy and Photometry of the Intergalactic Medium's Diffuse Radiation* (SPIDR). *Swift*'s goal is to determine the origin of gamma ray bursts, the most powerful explosions known to occur in the Universe. This mission will search for bursts in the x-ray, UV, optical, and gamma ray regions of the electromagnetic spectrum. The main goal of the *Spectroscopy and Photometry of the Intergalactic Medium's Diffuse Radiation* (SPIDR) mission is to determine the distribution of dark matter in the Universe by looking at the emissions from hot gas in the intergalactic medium. The density and temperature of these hot gases are dependent upon the amount of dark matter co-existing (but not visibly seen) with them. SPIDR will thus be able to indirectly measure the presence of this unseen component that has played such a crucial role in the formation of structure in our Universe.

Unique Structure and Evolution of the Universe Technology Requirements

The *Beyond Einstein* program demands many improvements in technology. *Constellation-X* will need lightweight optics and cryogenic x-ray calorimeters. To keep the *Laser Interferometer Space Antenna*'s test masses free of nongravitational forces, sensitive positional monitoring units coupled to micronewton thrusters are required; it will also need very stable laser measurement systems. These will enable changes in distances between spacecraft, separated by millions of kilometers, to be measured to values *smaller than the size of a proton*. This incredible accuracy is required if we are to detect the gravitational radiation in space that is theoretically predicted. The vision missions, a black hole imager and a big bang observer need still greater precision in spacecraft pointing and control. The *Einstein Probes* require study of a broad range of technologies, such as large-array microwave bolometers and giga-pixel optical/infrared detectors, so that the most effective approach to their science goals can be chosen.

4.3 Principles and Policies

Our approach to accomplishing Enterprise Science Goals is founded on a set of fundamental principles that encompass the role of space science within NASA, program planning and structure, project management axioms, our relationship to our scientific stakeholders, the role of technology, our responsibilities to the public, and guidelines for international cooperation. This section presents these principles.

Use scientific merit as the primary criterion for program planning and resource commitment. The scope of NASA's mission as provided in the Space Act of 1958 ranges from pure knowledge to advancing the state of practical know-how in many areas for the benefit of U.S. industry. The Space Science Enterprise is first and foremost a science program, among many activities conducted by NASA. In this context, NASA's space science programs also contribute to the other national purposes as secondary

objectives. The primary means for establishing merit for Enterprise programs are open solicitation and competitive peer review.

Base the Enterprise strategy on Agency science objectives and structure its research and flight programs to implement these objectives. These plans are developed every three years. Science goals are set in partnership with the scientific community, and mission formulation is based on these science goals within policy and budget constraints established by the Administrator, the President’s Office of Management and Budget (OMB), and the Congress. In planning, the first rule is to complete missions already started, except in the case of insuperable technical or cost obstacles. The Enterprise defines missions via its strategic planning process (often larger missions) and incorporates missions formulated by the scientific community (e.g., Explorer, Discovery, Mars Scout, and New Frontiers).

Aggregate consecutive missions that address related science goals into “mission lines.” It is much easier to explain broad science goals and a program of related missions to Agency stakeholders and the general public than it is to convey the significance of individual missions, which is often much more technical. Further, a stable funding profile for a series of related missions promotes continuity and flexibility in budget and technology planning. In structuring the flight program into mission lines, the first priority is to preserve and extend existing lines. The second priority is to develop and establish new mission lines corresponding to high priority Science Goals. .

Preserve safety as NASA's number one priority for robotic flight projects; this includes mission success and the implementation of controls on potential biological contamination from missions to or from other worlds. Projects will not be approved for implementation until a clear technology path to successful implementation is demonstrated. Each Enterprise flight project will maintain reserves appropriate to its level of technical risk, and testing and reviews will be adequate to provide positive engineering assurance of sound implementation. Resource shortfalls will not be relieved by deviating from proven safety, engineering, and test practices.

Ensure active participation of the research community outside NASA because it is critical to success. The outside community contributes vitally to strategic and programmatic planning, merit assurance via peer review, mission execution through participation in flight programs, and investigations supported by research grants programs. In addition, NASA science and technology programs conducted at the universities play an important role in maintaining the nation’s academic research infrastructure and in supporting the development of the next generation of science and engineering professionals, whether they pursue space research careers of their own or apply their technical skills elsewhere in the economy.

Ensure vigorous and timely interpretation of mission data, Enterprise programs require that data acquired be made publicly available as soon as possible after scientific validation. Other than in exceptional cases, data must be released within six months of acquisition and validation. In addition, Principal Investigators are required to publish their results in the peer-reviewed literature.

Maintain essential technical capabilities at the NASA Centers. NASA has significant scientific and technological capabilities at its Centers. NASA Center scientists provide

1 enabling support to the broader research community by serving as project scientists and
2 operating unique center facilities, and compete with external researchers for funding to
3 conduct their own original research. Center staff maintain “corporate memory” for
4 Enterprise programs and provide essential engineering support as well.

5 **Apply new technology aggressively, within the constraints of prudent stewardship of**
6 **public investment.** From its beginning in the 1950s, research in space science has
7 pushed the boundaries of our technical capabilities. The relationship between science
8 and technology continues to be bi-directional: scientific goals define directions for future
9 technology investment and development, while emerging technology expands the frontier
10 of possibilities for scientific investigation. To maintain the balance between risk and
11 reward, new technologies are demonstrated, wherever possible, via validation in flight
12 before incorporation into science missions. This policy is implemented through the New
13 Millennium Program, in which technology demonstration is the primary objective and
14 science plays a secondary role.

15 **Convey the results and excitement of our programs through formal education and**
16 **public engagement.** A fundamental consideration in planning and conducting all of our
17 programs is the recognition that the national investment in space science is a public trust.
18 This commitment encompasses not only print and electronic news media, but also
19 museum and other exhibits and material for formal pre-college education. To ensure
20 infusion of fresh results from our programs into these education efforts, our policy is that
21 each flight project must have an education and outreach component. The Enterprise has
22 established a nation-wide support infrastructure to coordinate the planning, development,
23 and dissemination of educational material, and works closely with NASA’s Education
24 Enterprise.

25 **Structure cooperation with international partners to maximize scientific return**
26 **within the framework of Enterprise strategic plan priorities.** The Space Act of 1958
27 provides that NASA shall cooperate in peaceful space activities with other nations.
28 Today, most of the Enterprise’s flight programs have international components. In
29 establishing these cooperative relationships, as indeed in all other aspects of our program,
30 funding is allocated to U.S. participants in international programs through competitive
31 peer review. Foreign participants in U.S. missions are likewise selected on the basis of
32 merit. In general, NASA seeks to lead where possible, and participate with our partners
33 through collaborative roles in other deserving areas.

5. KEY TECHNOLOGY REQUIREMENTS

As previously discussed in the Theme programs, each discipline has special, critical technology requirements. In addition, there are technology needs common to all space science endeavors. This section presents a summary of both the unique and the common, all of which are strategic investments in our ability to meet our Objectives.

The next generation of space science spacecraft will continue to be more capable, more reliable, but must remain affordable. New technologies are needed to endow spacecraft with more on-board power for greater communication bandwidth, data analysis and autonomy. Propulsion capability must be increased to reach deep space more with more capable payloads, in less time, with the ability to carry out a wider range of scientific programs. New telescopes require much larger apertures and higher resolution. Constellation technology must be developed to permit collecting data efficiently and simultaneously at dispersed locations. All of space science depends on continuing advances in sensors and detectors in the areas of sensitivity, accuracy and wavelength range. Significant reduction in the power and mass required for new instruments will also enable cost-effective and pervasive monitoring of the near-Earth environment and the solar system, leading to new scientific understanding. Many of these capabilities will also be invaluable for a future program of integrated human and robotic exploration.

During the preparation of the Enterprise Strategy, the Theme roadmap teams derived the key technical capabilities needed to implement their missions. The capabilities are synthesized into the Technology Blueprint — and summarized here— under three main headings: Observatory Technology, Technology for *in situ* Exploration, and Multi-Mission Technology. The Technology Blueprint is updated and issued semiannually to reflect changes of requirements and technology advances.

	Enterprise Themes					Astrobiology
	Solar System Exploration	Mars Exploration	Sun-Earth Connection	Astronomical Search for Origins	Structure and Evolution of the Universe	
Observatory Technology						
Optics: lightweight mirrors and active optics			X	X	X	X
Coolers			X	X	X	
GNC: constellation control, metrology			X	X	X	
In Situ Technology						
Robotics and planetary access	X	X				X
Power for surface systems	X	X				X
Entry, descent, and landing	X	X				X
Ascent	X	X				X
GNC: rendezvous and sample capture	X	X				X
Technology for extreme environments	X		X			X
Planetary protection and sample handling	X	X				X
Multi-mission Technology						
Avionics	X		X		X	
Communications	X	X	X	X	X	X
GNC: includes pointing, disturbance reduction	X		X		X	X
Information technology/Autonomy	X	X	X	X	X	X
Power	X	X	X		X	
Propulsion	X	X	X		X	
Structures/materials	X		X	X	X	
Thermal control and environmental effects	X	X	X		X	
Sensors/instruments	X	X	X	X	X	X

GNC: Guidance, navigation, and control

5.1 Observatories

The observatories of the future require higher spatial resolution, improved sensitivity, and efficient use of focal plane information. These requirements can be met by technology advances in four subsystem areas: space optics, constellation control, advanced coolers, and advanced sensors and instruments. Each of these new subsystems requires advances in several technical disciplines: optics, controls, structures, materials, nano-technology, coatings, information processing, microelectronics, thermal engineering, and system analysis and modeling.

The part of a telescope that dominates all other components is the primary mirror. New **space optics** concepts, coupled with advanced materials and structures are needed to achieve larger apertures for higher resolution with much lower mass than can now be achieved. The large primary mirrors for new space telescopes do not fit within launch vehicles and need to be made and launched as segments, to be deployed, reassembled and aligned to the required sub-micron optical tolerances in space to simulate a continuous precision optical surface. For some applications, large primary mirrors can be “synthesized” by utilizing constellations of smaller apertures, each on a separate spacecraft and controlling the optical beams passing between them using **interferometry**. Each of the separate spacecraft in the constellation needs to be precision controlled. Furthermore, advanced active wavefront metrology and control will allow taking advantage of segmented, sparse/synthetic, and interferometric aperture systems in excess of 20 meters in diameter.

The challenge in **constellation control** is to achieve precision positional and pointing accuracy for each element of the constellation. This, in turn, requires very high precision micro-thrusters and systems for sensing, metrology and control. With constellation population numbers in the several tens or hundreds of spacecraft autonomous, teaming techniques must be developed.

Advances in long-life **cryocoolers** and **space-radiative coolers** are needed to control the unwanted background radiation and noise at the focal plane.

Advanced sensors, particularly sensors with higher response in the far infrared region of the spectrum and low noise are essential for the observatories of the next generation. **Spectroscopy** is required to discover extra-solar system planets suitable for the support of life, and to understand the chemistry and physics of the gas and dust cloud surrounding a star in the planetary system formation stages of its evolution. New technology for spectroscopy and detectors is needed to optimize instrument performance when used with the new ultra-large space-telescope systems.

5.2 *In situ* Exploration

In coming decades, planetary exploration will change its focus from remote observation to *in situ* exploration and sample return missions. The key requirements for *in situ* measurements are in entry, descent and landing, robotics and planetary access, planetary protection, rendezvous and sample capture, and technology for extreme environments.

The most pressing need in **entry, descent and landing (EDL)** is safe, accurate autonomous landing on the surfaces of planets and small bodies. EDL techniques for small bodies and large bodies, and bodies with and without an atmosphere are significantly different.

Robotics and Planetary Access includes: surface mobility and subsurface access. Increasing autonomy is the key to longer traverses with rovers on Mars. Aerial systems are needed for missions to Titan and Venus. Aerial systems, such as balloons and aircraft, at Mars can enable unique geophysical and atmospheric measurements, which are feasible neither from orbit nor from a surface mobile vehicle. Subsurface access, by means of drills, penetrators and impactors, is vital to the investigation of sedimentary

climate records on Mars and for investigations of water and other volatiles on Mars and other planetary bodies.

Planetary Protection and Sample Handling are needed to avoid transporting Earth-organisms to planetary bodies that could contaminate the planet, appear in returned samples, or interfere with *in situ* instruments attempting to detect life. **Instruments** are needed to detect organisms at extremely low levels, along with robust cleaning methods for spacecraft. After samples are returned to Earth, they must be secured to prevent inadvertent release of potentially harmful material.

Autonomous Rendezvous and Sample Capture is needed for sample return missions, and requires the ability to locate, track and capture autonomously a small sample canister in orbit or deep space for return to Earth.

Development of **Technologies for Extreme Environments** is critical for *in situ* missions. Access to the surface of Venus, and to depths in the Jupiter atmosphere at which definitive measurements of bulk composition are possible, requires systems tolerating pressures of 100 bars, where temperatures approach 500C, and resilient to extreme deceleration loads during planetary entry. For missions to the Jupiter system that use nuclear propulsion, we will need radiation hardening to increase spacecraft tolerance to both the natural radiation of the Jupiter environment and the neutron radiation of the power source.

5.3 Multi-Mission Technologies

The multi-mission technology category serves all space science flight programs. It encompasses nine classic disciplines that make up a modern space system: Communications, Sensors/Instruments, Propulsion, Power, Avionics, Information and Autonomy, Guidance and Control, Thermal Control and Environmental Effects, Structures and Materials.

Communications data transfer rates are a major limiting factor on science return from space missions, especially from spacecraft at planetary distances. Increased data rates are a critical need that may be met by emerging technology in X and Ka-

Optical Communications

Limitations in the present deep-space communications rates (S, X, Ka bands) are a bottleneck to scientific discovery and public outreach. Use of optical/laser communications technology will enable dramatic improvements in science data rates and will lower the cost per byte of data returned. The Optical Communications Initiative will demonstrate critical space and ground technologies in this decade and perform a flight demonstration in the next. The purpose is to demonstrate high-data-rate communication from Mars in the 2010 timeframe. Optical communications' potential must be demonstrated and quantified under operational scenarios.

The Optical Communications Initiative will develop technologies enabling return of much greater quantities of scientific data from long-duration science missions such as the Jupiter Icy Moons Orbiter. This new class of exploration missions, powered by nuclear fission, may include tours of multiple targets, extended orbital and surface stay times, and high-power science instruments—all of which lead to much larger quantities and higher rates of data return.

To make optical communications an operational program we would need to complete the technology development of high-power lasers that will be capable of delivering vast quantities of scientific data from deep space missions. We would also need to develop the infrastructure of ground optical receivers to complement the Deep Space Network.

bands, as well as optical communication. The Enterprise is leading a new initiative to develop optical communications capabilities. Data compression tools and increased local communications capabilities are also needed.

Sensor and instrument technology progress is needed to provide new observational capabilities for astrophysics, space physics, solar and planetary science remote sensing, as well as vehicle health awareness. Focal plane arrays that cover a larger area with a large number of pixels are needed to examine larger areas of the sky for both efficient operation and to measure the dynamics of complex phenomena. Large area, high efficiency, high read-out speeds are needed for deep-sky surveys.

Power and propulsion technology needs include higher efficiency power systems, advanced chemical and solar electric propulsion, micro-propulsion systems, solar sails, and aerocapture. The Nuclear System Program, which focuses on advanced radioisotope generators and space qualified nuclear reactors, is a major development for meeting these requirements. Project Prometheus will also develop advanced power conversion and propulsion subsystems that will be applicable across a broad range of missions.

1

Project Prometheus

Project Prometheus will develop the means to efficiently increase power for spacecraft, thereby fundamentally increasing our capability for Solar System exploration. Increased power for spacecraft means not only traveling farther or faster, but it also means exploring more efficiently with enormously greater scientific return. High levels of sustained power would permit a new era of outer Solar System missions designed for agility, longevity, flexibility, and comprehensive scientific exploration.

Pending approval by Congress, NASA's Project Prometheus would develop the technologies needed to enable the above vision for the future. There are two basic types of technology under consideration for this program: (1) radioisotope-based systems and (2) nuclear fission-based systems.

Radioisotope Power System (RPS) development would focus on two technologies, the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) and the Stirling Radioisotope Generator (SRG), that are expected to improve the efficiency and utility of systems that NASA has been using for 30 years. These essential improvements on our current technology would enable "all weather, anywhere, anytime" exploration of planetary surfaces.

The fission power and propulsion research would focus on developing the nuclear systems needed for revolutionary new capabilities in space exploration. Project Prometheus would include research on reactors, advanced heat-to-power conversion, and power management and distribution technologies to provide spacecraft flexibility, long-mission durations, and orders of magnitude more power for science instruments.

Project Prometheus will be a NASA program with substantial involvement of the U.S. Department of Energy (DOE). NASA would define the science requirements for future exploration missions and manage the RPS and fission-based programs, as well as the spacecraft systems engineering. A substantial portion of Project Prometheus research and development would be competitively awarded.

The initial activity related to RPS program would concentrate on developing the MMRTG and SRG systems (either of which could be of potential use on the Mars Smart Lander Mission to be launched in 2009). The fission power and propulsion program would focus on defining the near-term technology research goals, and has identified a planetary science mission that will be uniquely enabled by nuclear fission electric power and propulsion: the Jupiter Icy Moons Orbiter. The Jupiter Icy Moons Orbiter will be an ambitious mission to orbit three planet-sized moons of Jupiter -- Callisto, Ganymede and Europa -- which may harbor vast oceans beneath their icy surfaces. The mission would orbit each of these moons for extensive investigations of their makeup, their history and their potential for sustaining life.

In addition a range of technologies and system designs will be explored that may be prudent for NASA and DOE to invest in over the next several years, beyond the specific technologies already under consideration. NASA and DOE would also identify and recommend additional strategic technology investments to potentially enable future human exploration of the Solar System.

In keeping with NASA goals of openness and transparency, Project Prometheus would seek to ensure open, inclusive dialogue and engagement with the public, media, educators, legislators, and others; foster technology education and outreach programs; and make appropriate materials available on the Internet.

2

3 Technology needs in **Avionics** include: high-performance yet power-efficient processors,
4 Memory, Sensor Interfaces, Data Bus and Architecture, Packaging and Interconnects.

1 **Information and Autonomy** technology typically involves shifting decision-making
2 from the Earth to the spacecraft. There is also need for more on-board responsibility in
3 housekeeping (monitoring, diagnosis and response). Key areas that are being addressed
4 include autonomy, reliable software, modeling and simulation, improved onboard
5 computational resources, science data analysis and knowledge discovery. The pace of
6 development in information technology is unparalleled, leading to a significant lag in
7 infusion of state of the art techniques into SSE missions. Steps have been undertaken to
8 quicken the infusion process for new IT.

9 Needs for **Guidance, Navigation and Control** (GNC) technology include sensors and
10 actuators with unprecedented precision, and the ability to reduce spacecraft disturbances,
11 trajectory design, flight path estimation, metrology, and attitude control. Trajectory
12 design technology is particularly needed for solar electric propulsion and solar sail
13 missions. Flight path estimation is needed for in situ missions involving aerobots or
14 landers.

15 **Thermal Control** needs run the gamut from protection of spacecraft and instruments
16 near the Sun or at Venus to cold environments at outer planets or near comets to
17 spacecraft accommodation of cooled detectors and optics on observatories.

18 **Structures and Materials** needs include light structures that retain strength, stability,
19 and stiffness, balloon materials for harsh environments, membrane materials and booms
20 for gossamer structures such as solar sails and large apertures, multi-function spacecraft
21 structures, and simulation and test of material performance and durability in space.

22

6. RESOURCE REQUIREMENTS

The Office of Space Science has unique requirements in the areas of human, capital, and information resources. These requirements are tied to the special science and engineering skills needed to postulate science questions; develop missions, experiments, and instruments to answer them; and analyze and interpret the data. They also encompass the need for specialized facilities and infrastructure for the building and testing spaceflight hardware and storing, managing and distributing science data and results.

6.1 Human Resources

Our most important resource and the key to our success are NASA's workforce and the members of the space science communities, and our partners, the aerospace industry scientists and engineers. NASA's Space Science Enterprise needs the ability to develop the human resources necessary to enable us to reach our Objectives and to foster the abilities of our partners and allies to also develop their own human resources.

As is emphasized in the *Space Science E/PO Implementation Plan*, "meeting the future needs of a society based on science and technology will require the involvement of individuals from groups who, at the current time, are not as effectively utilized as they should be in science and technology. This is an urgent matter of national self-interest, not a matter of 'political correctness.' The issue is not just one of ensuring the future supply of scientists and engineers. It also involves the need to educate all people about the important role that science and technology plays in their lives."

To meet our Objectives the Enterprise requires the talents of people from a broad range of disciplines including the sciences, engineering, mathematics, and information technology. In some areas we cannot achieve our Objectives unless individuals are inspired to earn advanced degrees in new fields, such as gravitational physics (to support the LISA mission), or in fields that have experienced reduced interest in the last several decades, such as nuclear engineering (to support the Project Prometheus). We also need to be able to adequately employ these individuals by offering competitive wages and working conditions. Government salaries often cannot compete with those of industry, and NASA has been unable to fill essential positions, creating a human resources gap that will become a critical issue in this decade.

The Space Science Enterprise seeks to reach and encourage the next generations of scientists, mathematicians, and engineers through education at all levels, public outreach, support of promising graduate and undergraduate students, and young researcher grants.

6.2 Capital Resources

Our unique missions and technical challenges require a variety of capital resources, from communications networks to specialized test facilities. Among these are the Deep Space Network, planetary sample curation facilities, and the simulation and test facilities for missions such as Hubble or the James Webb Space Telescope.

1 The NASA Deep Space Network (DSN) is an international network of antennas that
2 supports interplanetary spacecraft missions and radio and radar astronomy observations
3 for the exploration of the solar system, the universe and selected Earth-orbiting missions.
4 The DSN currently consists of three deep-space communications facilities placed
5 approximately 120 degrees apart around the world: at Goldstone, in California's Mojave
6 Desert; near Madrid, Spain; and near Canberra, Australia. This strategic placement
7 permits constant observation of spacecraft as the Earth rotates, and helps to make the
8 DSN the largest and most sensitive scientific telecommunications system in the world.
9 The antennas and data delivery systems make it possible to acquire telemetry data from
10 spacecraft, transmit commands to spacecraft, track spacecraft position and velocity,
11 perform very-long-baseline interferometry observations, measure variations in radio
12 waves for radio science experiments, gather science data, monitor and control the
13 performance of the network. The instruments flown on spacecraft are now capable of
14 taking more data than the DSN can capture. Increased aperture capacity and wider
15 bandwidth are required to enable and optimize NASA science in the coming years.

16 Solar System samples are precious assets for detailed study in terrestrial laboratories.
17 Current collections include lunar samples—still actively studied 30 years after Apollo,
18 Antarctic meteorites, and interplanetary dust particles. Facilities are being constructed to
19 receive, process, and store samples of the solar wind from Genesis and of comets and
20 interplanetary dust particles from Stardust. Future sample return missions will require
21 the establishment of specialized laboratories to ensure that the highest quality science can
22 be done on the samples. A major challenge will be construction of a “clean” bio-
23 containment facility for returned Mars samples.

24 The Enterprise relies on spacecraft and instrument integration and test facilities and
25 antenna test ranges at the Jet Propulsion Laboratory and Goddard Space Flight Center.
26 The Hubble Space Telescope simulation and test facility at Goddard is representative of
27 test facilities around the country needed to ensure on-orbit success for large space science
28 missions. This facility is particularly important during the testing and commissioning of
29 new instruments.

30 We also use balloon and aircraft test capabilities at the NASA Centers, including wind
31 tunnels at the Ames and Langley Research Centers. Among Center capabilities, NASA's
32 sounding rocket infrastructure at the Wallops Flight Facility is unique in the country. The
33 Wallops launch range includes six launch pads, three blockhouses for launch control and
34 assembly buildings that support the preparation and launching of suborbital and orbital
35 launch systems.

36 Finally, launch facilities, such as those at the Kennedy Space Center, are critical to all
37 space missions, including those that perform space science. The Vehicle Assembly
38 Building (VAB) and two Shuttle launch pads at Launch Complex 39 may be the most
39 well known structures at Kennedy, but other facilities also play critical roles in prelaunch
40 processing of payloads and elements of the Space Shuttle system, including planned
41 Space Station Freedom activities.

6.3 Information Resources

The Space Science Enterprise has a strong tradition of user-driven data systems that include systematic processing, archiving, and accessibility of data from its missions. Public archives that typically open one year after the data are first distributed ensure the widest possible exploitation. New information technologies (IT) such as the worldwide web have been embraced to maximize access and increase the productivity of the user community.

Future science information and data systems will continue to exploit the opportunities provided by advances in both the hardware and the software IT environment. The immediate future is being driven by continued dramatic reductions in the cost of data storage, low cost and powerful desktop computing, and emerging standards underlying the worldwide web and associated technologies. This is enabling rapid access to large volumes of data, interoperability of data systems and archives, grid computing and data mining.

The “virtual observatory” concept is one representation of the intersection of these technologies. It allows for exploration and data mining across the widely distributed federation of multi-terabyte datasets in a transparent manner. Theoretical modeling and numerical simulations, as well as assimilation of observational data into the models will be enabled within the “virtual observatory” environment. The requirements design and implementation of these virtual observatories will follow the successful formulation applied in the past by the Enterprise, i.e. they will be driven by the requirements of future missions, the needs of the user communities, and realization of the overarching science goals of the science themes. This framework will build upon and evolve from the current successful science program-specific capabilities, including the Planetary Data System, the astrophysics wavelength-oriented science archive research centers, the Solar Data Analysis Center, and the multi-discipline National Space Science Data Center.

Opportunities to coordinate with related activities in other federal agencies and international partners will be encouraged. For example, the National Virtual Observatory initiative funded by NSF has substantial involvement by the NASA astrophysics data centers and will allow seamless access to both space and ground based astronomical data. Within the Sun-Earth Connection Theme, the emerging Virtual Solar Observatory initiative being developed by the international solar physics community has as one of its foundation elements the Solar Data Analysis Center.

APPENDICES

A-1 RELATIONSHIP TO THE AGENCY PERFORMANCE PLAN

As a federal agency, NASA is required by the Government and Performance and Results Act of 1993 (GPRA) to prepare a five-year strategic plan and update it every three years. Each of NASA's Enterprises develops its own strategic plan on the same schedule. Other requirements of the GPRA are that agencies also develop yearly performance plans and performance reports. An agency performance plan is aligned and delivered with the agency's budget and explains what progress the agency expects to make during the upcoming fiscal year against goals and objectives in its longer-term strategic plan with the requested appropriation. At the end of the fiscal year, the annual GPRA performance report compares agency performance during the year against the projections provided in that year's performance plan.

Document	Cycle (years)	Required by GPRA Statute?
Agency Strategic Plan	3	Yes
Enterprise Strategic Plans	3	No
Agency Performance Plan	1	Yes
Agency Performance Report	1	Yes

The Enterprise strategic plans provide more detail about their Objectives and activities than the Agency-level plan. Thus, while not required by statute, the Enterprise plans are supporting elaborations of the Agency strategic plan and are thereby integrated into the NASA GPRA performance management system. At the level of detail provided in NASA's Agency plan, it is difficult to assess and represent progress on an annual basis. Therefore, the Enterprise uses a more detailed breakdown of its Strategic Objectives into Research Focus Areas (RFAs) for this purpose. The RFAs (shown in Appendix) are also used in investigation solicitations to inform potential proposers of scientific areas of primary Enterprise interest.

The proposed outcomes and FY 2004 annual performance goals have been submitted with the Performance Plan as part of the FY 2004 budget in an Agency Integrated Budget and Performance Document. NASA will improve the quality of these measures, and our Objectives as necessary, making them more quantifiable and verifiable, and it will release an updated FY 2004 performance plan prior to September 15, 2003. NASA also plans to release an updated FY 2003 performance plan that is consistent with this new strategic plan and the new strategic framework for budget and performance integration. In order to make performance planning an integral part of how the Agency is managed, NASA will incorporate the performance planning process into our annual budget formulation or program operating plan development process. Preparation of the FY 2005 budget request will be the first formal development cycle tasked with defining the outcomes and annual performance goals for each theme.

1 **A-2 KEY EXTERNAL FACTORS**

2 To accomplish its objectives, the Space Science Enterprise relies on contributions from a
3 great diversity of partnerships. Closest to home, this includes relationships with other
4 enterprises that are governed by the “One NASA” principle. Sound management practice
5 attempts to reduce or eliminate duplication of functions within the Agency. .

6 From here, the circle of partnerships extends beyond NASA, to other government
7 agencies with charters and capabilities different from NASA’s but still essential to space
8 science programs. Researchers in the university community have played a central role in
9 NASA’s space science program since the founding of NASA, and a large corps of
10 external organizations have more recently become actively involved in the Enterprise’s
11 broad and vigorous education and public outreach program. In implementing its
12 competitive sourcing mandate, NASA looks to industry to purchase goods and services of
13 all kinds, so their availability from the private sector is essential for success.

14 The Space Science Enterprise’s cooperative relationships with foreign space agencies
15 deserve special mention. Provisions to international partnerships were explicitly
16 highlighted in the Space Act of 1958, NASA’s founding charter, and the intervening four
17 decades have seen a long series of extremely fruitful joint scientific activities that have
18 enormously enriched the U.S. space science programs.

19 **Inter-Agency Dependencies** The Space Science Enterprise has established and
20 maintains active relationships with a number of other federal agencies and programs. In
21 some of these relationships, NASA is a customer, in some a collaborator.

1 ***The Space Science Enterprise relies on external organizations for support in critical areas.***

	NSF	DoE	DoD	DoC	State Dept.	Universities	Industry	E/PO Partners	International	NRC
Joint science funding	X								X	
Science instruments	X	X				X			X	
Science expertise	X					X			X	X
Research facilities, labs			X	X		X			X	
Technology	X	X				X	X			
Launch vehicles			X				X			
Antarctic facilities	X									
Radiation-hardened parts							X			
High-density power systems		X								
Nuclear materials		X								
Shared launch facilities			X							
Operational data (weather, etc.)			X	X						
Operational requirements			X	X						
Satellite tracking			X							
Int'l approval				X	X					
Peer review						X				X
Advisory committees						X				X
Education expertise	X					X		X		
Exhibition expertise	X							X		

2

3 **National Science Foundation** As the two primary federal agencies involved in the
4 support of astronomy, solar physics, and other space sciences, NASA and the National
5 Science Foundation (NSF) have a broad portfolio of past, current, and future
6 collaborations. Many Enterprise programs are dependent on the support and sponsorship
7 of NSF. Currently, NASA and NSF jointly fund planet search programs, astrobiology
8 science and technology investigations for exploring planets, long-term interdisciplinary
9 studies of life in extreme environments, ground-based investigations in support of
10 NASA's *Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics* TIMED
11 mission, and technology development for the National Virtual Observatory. NSF and
12 NASA bring complementary strengths to each joint program.

13 NSF is also responsible for supporting U.S. scientific activities in the Antarctic. In
14 partnership with the Smithsonian Institution, NSF and NASA collaborate on the search
15 for, collection, distribution, and curation of Antarctic meteorites. NASA and NSF have a
16 joint program to use Antarctica as an analog for the space environment in developing
17 long-range plans for Solar System exploration. NSF provides operational and logistical
18 support for annual Antarctic ballooning campaigns, including NASA's long-duration
19 balloon missions. None of these activities would be possible without the stewardship role
20 that NSF performs for Antarctic-based research programs.

Department of Energy The Department of Energy is an essential partner to many NASA space science activities. The DoE has provided high-density power systems to NASA for more than 30 years. Radioisotope Thermoelectric Generators, built and provided to NASA by DoE, enabled a wide range of Solar System exploration missions—from Apollo and Viking to Voyager, as well as the Galileo and Cassini-Huygens missions. As NASA’s contractual partner for the Project Prometheus, the DoE is responsible for the research and development for the next generation of radioisotope power systems and for developing space fission reactors. The DoE works with NASA to improve the efficiencies of many power and propulsion systems, such as the Stirling radioisotope generator (SRG). These Stirling generators are a new generation of lighter and smaller radioisotope power system that will provide a more than 25% increase in power from the same amount of fuel as current radioisotope power systems. For higher power systems, the DOE will support the Project Prometheus with research on reactor design and on power conversion interfaces.

The DoE also develops instruments and sensors for NASA’s space science missions, particularly through its Lawrence Livermore and Los Alamos laboratories. Data from DoE missions also supports the International Solar Terrestrial Physics Program.

Department of Defense The Enterprise and the Department of Defense (DoD) rely on each other programmatically and scientifically. Shared launches, shared satellites, and joint use of facilities enable us to function more efficiently and effectively with limited resources. The agencies share scientific and practical interests in forecasting the sometimes-disruptive effects of space weather on communications, navigation, and radar and in understanding the constraints that variable conditions in space near Earth place on spacecraft design, reliability, and control. The DoD, like the Department of Commerce, has an operational interest in space weather models and data. Transferring measurement techniques, expertise, and codes for modeling and forecasting from research to implementation and operations is a challenge that NASA, DoD, and other agencies must overcome together. A part of the solution is the multi-agency Community Coordinated Modeling Center (CCMC) that supports the transition.

NASA’s Living With a Star (LWS) program relies on DoD to help set research priorities to address challenges that come from increased reliance on space and space-weather-sensitive systems. The LWS Space Environment Testbeds program depends on DoD for launch opportunities and payloads. OSS researchers depend on data from DoD satellites, such as the Solar Mass Ejection Imager that will be launched on a Space Test Program mission, and from ground-based observing networks, such as ISOON (the Improved Solar Observing Optical Network). Laboratories sponsored by the Office of Naval Research and the Air Force Office of Scientific Research provide invaluable scientific, technical, and engineering expertise for many NASA programs.

Department of Commerce Since many research missions include important contributions from international co-investigators, Export Administration Regulations (EAR) administered by DoC affect foreign partnerships that are a key to many OSS programs. This issue will continue to be significant during the implementation of future collaborative research missions, include those that are part of the newly formed International Living With a Star program. Many NASA investigations depend on

Department of Commerce (DoC) facilities, such as the National Institute of Standards and Technology (NIST) for standards for calibration of instruments.

Natural variability investigated by the Sun-Earth Connection (SEC) Division, particularly the Living With a Star (LWS) Program, affects the environment in ways that are of great practical interest to commercial and security-related users of DoC information. SEC partners with elements of the DoC, such as the National Oceans and Atmospheric Administration's Space Environment Center (NOAA/SEC) for collection, analysis, and dissemination of data; it provides data models and analysis tools for use by the DoC; and relies on NOAA for solar remote sensing observations and *in situ* magnetospheric data from NOAA space-based systems, such as the solar soft x-ray imagers and monitors on new Geostationary Operational Environmental Satellites (GOES). NASA's strategic plan does not call for a replacement of existing instruments the monitor solar wind conditions at L1 – about one hour flow time upstream of Earth in the solar wind – when the current research missions terminate. NASA spacecraft can provide useful space weather data for operations even after their most productive scientific mission lifetimes; NASA would like to work toward a scenario in which DoC would assume responsibility for such spacecraft in this geophysically important location. Transitioning space weather forecasting models developed under the auspices of the LWS program for use by NOAA/SEC forecasters remains a significant challenge that requires continuing and increasing coordination with DoC laboratories and researchers.

Department of State The mandate to partner with other countries in the peaceful uses of outer space is written into NASA's charter, the Space Act of 1958. Since the Department of State has overall responsibility for managing U.S. relationships with other countries, there are many areas where NASA depends directly on the Department for information, services, and oversight. NASA depends on the Department for guidance on official government policy toward other individual countries and the role of space cooperation in the U.S. relationship with them.

On the operational level, the State Department has statutory authority for approving negotiation and conclusion of all international agreements. As part of this responsibility, the State Department administers an inter-agency review process (the C-175 process) for international agreements. The Department is also responsible for administering the provisions of the International Traffic in Arms Regulations, including related exemptions and licenses. Because all "space systems" and most associated equipment and technologies are subject to these Regulations, NASA and its investigator community and industrial contractors are closely tied to the Department of State for compliance with these Regulations.

The Universities Universities play a crucial role in achieving the Space Science Enterprise Objectives. University investigators, who perform basic research and analyze data from space science missions, win almost 70% of the funding for Research and Data Analysis program. Also, university scientists are often Principal Investigators of space science flight missions. Scientific experts from universities populate space science advisory committees, working groups, and peer review committees, providing essential advice and input. Finally, students and young investigators acquire training through the R&DA programs and evolve into instrument builders, Principal Investigators of major flight missions, and occasionally astronauts.

E/PO Cooperating Partners The NASA space science education and public outreach program complements the large investments in education being made by school districts, individual States, and other Federal agencies, particularly by the National Science Foundation and the Department of Education. We rely on partnerships with these organizations, as well as with education-oriented professional societies, education departments at colleges and universities, and major curriculum developers to leverage our space science content, technical expertise, and E/PO resources into efforts that have major national impact.

Typically we provide space science content and expertise while relying on our partners to provide the educational expertise, context, and infrastructure. For example, we develop major museum exhibitions in partnership with a host museum that provides expertise in presenting programs to the public together with the design, fabrication, publicity, and initial showing of the exhibition. The exhibition then typically goes on national tour under the auspices of an organization such as the Smithsonian Institution's Traveling Exhibition Service. We develop space-science-based curriculum materials in partnership with organizations such as the Mid-continent Research for Education and Learning (McREL) who provide the actual curriculum development, testing, and national dissemination.

Other partners assist us in extending the reach of our education and public outreach efforts. Such partners include educational and scientific professional societies such as the National Science Teachers Association, special interest organizations such as the National Organization of Black Chemists and Chemical Engineers, and community organizations such as the Girl Scouts. Public broadcasting documentaries and other such projects designed to reach large audiences are also leveraged in similar ways.

Finally, our most essential partners are the universities, laboratories, NASA Centers, and industry contractors who carry out our space science missions and research programs. Because our education and public outreach efforts are embedded within their missions and programs, these partners have the primary responsibility for developing and implementing education and public outreach projects that capitalize on the unique mission science and technology.

Industry The Space Science Enterprise is critically dependent on industry for: launch vehicles, spacecraft systems and infrastructure, and detector fabrication.

NASA's Space Science Enterprise does not manufacture or launch its own launch vehicles, but relies on purchasing these services from commercial vendors. As a result, available launch vehicles are limited to those with customers in the general marketplace. NASA's programs that require smaller spacecraft, which were dependent on vehicles developed for the now-foundering Low Earth Orbit communications constellations, are confronted with access-to-space difficulties.

For example, the current Delta-II vehicle is likely to be phased out in the 2009 time frame. It will be replaced by the Atlas-5 and Delta-IV. The Delta-IV will be a family of vehicles with a range of capabilities, but it is likely that the smallest will be significantly bigger and more expensive than the Delta-II.

For smaller spacecraft, the only proven, dedicated-launch option is the Pegasus launch vehicle. Because the general-market sales volume may be inadequate to warrant its continued availability, Pegasus's future is uncertain. The Athena vehicle, which successfully launched the Lunar Prospector, is no longer available. The Taurus vehicle is available, but has not flown enough to be considered "proven" and has not been used to date for a space science mission. While at one time, the Space Shuttle carried small payloads and spacecraft, due to changes in the program, it is not expected that the Shuttle will be available as a solution to any of these problems in the foreseeable future.

The only other option for small spacecraft is one of co-manifesting with another spacecraft and using a dual-payload adapter, which has been successfully launched on the Delta-II. However, this course routinely presents difficulties in coordinating development schedules and finding commonality in desired orbit. In addition, the loss of Delta-II launch vehicles leaves the Ariane-5 adapter as the only option for dual manifest. However, national launch policy precludes purchase of foreign launch services for U.S. government payloads. Atlas-5 and Delta-IV are believed to be developing a comparable capability, but there is currently no assurance that it will be realized.

Thus, access to space at a reasonable cost for space science missions is projected to become more difficult over time, and new options need to be investigated during this 5-year planning period.

The aerospace industry also plays a critical role in the design, engineering, manufacture, construction, and testing of both large and small space missions; in the design, development, testing, and integration of advanced instruments; and in the development of advanced spacecraft, instrument, mission operations, and information system technologies. Many industry capabilities have been developed for commercial applications with DoD or NASA core technology support. The resulting extensive space industry infrastructure is available for use for space science purposes.

The new generation of space science missions enabled by the Project Prometheus will need support from a series of related technological advancements that must be made in the industrial sector. Among these technologies are: radiation hardened parts or new forms of lightweight shielding, power management and distribution systems for autonomous operations at extreme distances and with significant time delays in communication, and system and component design for high reliability and extended life. NASA will rely on industry to provide these systems and components and more to enable missions to successfully reach the farthest reaches of the Solar System and beyond.

Foundries producing Charge Coupled Devices (CCDs) are gradually becoming extinct in the U.S. This means that space science investigators may have to change from proven and understood CCDs to Active Pixel Sensors for ultraviolet and visible astronomical detectors. Similarly, investigators often have to go overseas to acquire spectrometer/spectrograph gratings, which are no longer manufactured in the U.S.

International Cooperation Over its 40-year existence, NASA's space science program has engaged in literally hundreds of international cooperative activities. International cooperation brings several important advantages to Enterprise programs. First and foremost, it enables U.S. science to benefit from relevant expertise from around the world; this expertise includes not only synergistic capabilities in fundamental science, but

in engineering knowledge and technology how-to as well. Further, foreign co-investment in our flight projects, and U.S. co-investment in theirs, can often significantly enhance the capability of a flight mission by adding instruments or other otherwise unavailable enhancements.

International cooperation at NASA has been guided since the early 1960s by a uniform and unchanging set of principles. These principles, which have proven very successful over the years, have lent stability and predictability to our cooperative posture, essential for good planning.

NASA Principles for International Cooperation
--

Each participating government designates a central agency for the negotiation and supervision of joint efforts
--

Agreements are forged on specific projects rather than generalized programs

Each country accepts financial responsibility for its own contributions to joint projects

The projects are of mutual scientific interest
--

The cooperation provides for general publication of scientific results
--

To these general Agency principles, the Space Science Enterprise adds a few additional management guidelines. Opportunities for foreign cooperation in U.S. missions, as well as contributions by U.S. investigators to foreign missions, are subject to the same requirements for open and competitive selection based on peer review for science quality. Secondly, data obtained from missions conducted cooperatively between NASA-supported investigators and foreign entities should observe the same policies for prompt availability of data as apply to purely domestic U.S. projects.

The Enterprise's resulting cooperative arrangements are nearly always bilateral, even on programs that have multiple participants. Their legal framework and the parties' roles and responsibilities are documented in formal written agreements negotiated by NASA's Office of External Relations under the oversight of the Department of State.

1 **A-3 PROGRAM EVALUATIONS**

2 The Enterprise's programs are diverse and range from fundamental research and
 3 technology development to flight mission development and operations. Determining the
 4 best allocation of resources is a major challenge and requires deeper and broader
 5 expertise than the NASA can provide internally. As a result, the Enterprise depends on a
 6 wide spectrum of independent science and program status assessments to inform its
 7 decision making. A majority of the participants in these reviews are drawn from the
 8 scientific community outside of NASA, but NASA personnel and technical consultants
 9 may also play a role.

10 The evaluations span the range from merit evaluation of scientific proposals, through
 11 periodic assessments of science achievement and the status of the field, to strategic
 12 scientific and tactical programmatic recommendations.

13 **Peer Review of Proposals**

14 A bedrock principle for all of the Office of Space Science programs is that of peer review
 15 of the proposals submitted in response to open and broadly advertised research
 16 solicitations. Such reviews are carried out by panels of highly qualified scientists (for
 17 scientific issues), engineers (for technical issues), and managers (for financial and
 18 management issues), each of whom has been screened for their competence in their
 19 respective fields, as well as for freedom of conflicts of interest from the proposals that
 20 they are asked to examine. Typically every proposal is read in detail by several panel
 21 members and then discussed in open forum to arrive at a consensus opinion.

22 Although the details of the criteria vary depending on the nature of the solicitation, in
 23 general they can almost always be classified into one of three main categories:

- 24 • Scientific and/or technical merit including the competence of the proposer and the
 25 proposed plan of research;
- 26 • Relevance to NASA's Objectives as given in the solicitation; and
- 27 • Realism and reasonableness of the proposed cost and management plan.

28 Additional, subsidiary criteria may also be stated, for example, furthering NASA's
 29 objectives in education and public outreach, and the involvement of small and/or
 30 minority (including woman-owned) businesses.

31 The totality of these reviews are then combined using the stated priorities of these criteria
 32 to arrive at an overall figure of merit that is typically based on a five-point adjectival
 33 scale (Excellent, Very Good, Good, Fair, and Poor). A NASA Selection Official makes
 34 the final selection from among the best proposals as allowed by the available budget and
 35 for program balance as may be necessary to achieve the program objectives.

1 **Senior Reviews for Extended Operations**

2 With only a few exceptions most space science satellites are able to continue operating in
 3 a productive manner well after their nominal “prime” missions have been achieved and,
 4 therefore, return valid science data either for the refinement of their original objectives or
 5 to accomplish an entirely new set of objectives (e.g., the International Sun-Earth Explorer
 6 satellite was sent to study a comet after completion of its primary mission of studying the
 7 Earth’s magnetosphere). In spite of the fact that such extended operations are frequently
 8 fairly low cost compared to the prime mission, and typically only a few percent of the
 9 original cost of the mission itself, the amount of funds available to OSS for Mission
 10 Operations and Data Analysis (MO&DA) is limited by the NASA budget.

11 Therefore, in order to prioritize those missions that seek continued operation—perhaps as
 12 many as a half dozen or more—the Senior Review process was developed and is carried
 13 out every two years. A panel of distinguished, senior scientists who were not involved in
 14 the candidate missions are assembled to review in detail each mission that seeks support
 15 for continued operations and to recommend, in priority, order further MO&DA funding
 16 over the course of the next three years. This process has been carried out for the last
 17 decade and has proven to be a fair and accepted process by the science communities,
 18 even though it occasionally results in turning off an older satellite that is still capable of
 19 returning data. Alternatively, in a few such cases such missions have been turned over to
 20 non-NASA institutions, typically a university, to operate for training its students.

21 **Triennial Research Program Reviews**

22 Through its Research and Analysis (R&A) program budget, the Office of Space Science
 23 supports about three dozen separate subdisciplines of science spread over the three major
 24 science themes: astronomy, planetary exploration, and space physics, which includes the
 25 study of the Sun, interplanetary space, and planetary magnetospheres and ionospheres.
 26 As NASA’s missions have been carried out over the years these various subdisciplines
 27 have evolved in their relative degrees of maturity and pursuit of new frontiers in response
 28 to discoveries, and in a few cases even entirely new disciplines have emerged (for
 29 example, that of astrobiology). As a way of trying to evaluate the relative health and
 30 productivity of these various subdisciplines, OSS instituted a “Triennial Review” for the
 31 first time in early 2001, for which a multidisciplinary panel of distinguished, senior
 32 scientists reviewed in a systematic manner each of the science subdisciplines in terms of
 33 their recent accomplishments and their prognosis for new and exciting achievements in
 34 the near future. This panel produced a report that divided the disciplines into four broad
 35 categories based on (i) “most deserving” to receive greater proportion of the R&A
 36 budget, (ii) deserving of continued support with only a nominal (i.e., cost of living)
 37 increase in support, (iii) requiring improvement of in performance and, therefore, a
 38 candidate for a decrease in support, or (iv) being a candidate for a major decrease in
 39 support if not complete termination. This peer assessment was sufficiently successful in
 40 achieving its goals that it may be carried out again in 2004.

Committees Chartered under the Federal Advisory Committee Act (FACA)

NASA’s senior FACA-chartered advisory body is the NASA Advisory Council, which advises the Administrator. The Council has a number of subordinate committees that serve an analogous purpose for the Enterprises; the Space Science Enterprise’s advisory body, which reports to the Associate Administrator for Space Science, is the Space Science Advisory Committee (SScAC). The SScAC provides scientific, technical, and programmatic advice to the Enterprise on behalf of the broader outside research community. The Committee also serves to transmit information about policies and decisions of the Enterprise to its constituent research community members.

In addition, the SScAC has a major role in assessing the Enterprise’s scientific performance as part of the Agency’s annual GPRA performance report. Once a year the Enterprise prepares a self-assessment of the status of the space science program in terms of the Strategic Objectives and Research Focus Areas. The SScAC receives its subcommittees’ response to this self-assessment and delivers an independent assessment for incorporation into the Agency’s annual performance report.

The SScAC meets three times per year, as do each of three Theme science subcommittees. The chair of the Committee sits, *ex officio*, on the NASA Advisory Council, providing a conduit for the Committee’s views to be offered as independent advice at the Administrator’s level.

National Research Council

In addition to the input received from the SScAC, the Space Science Enterprise also solicits and receives independent advice from boards and committees of the National Research Council (NRC). Unlike the SScAC, the NRC appoints its own members and sets its own meeting agendas; the Agency’s only control over studies performed by the NRC is to set their terms of reference and negotiate a schedule and cost for the studies. Particularly valuable reports developed by the NRC are the “decadal surveys” carried out in the various fields of space science. These surveys engage large parts of their constituent scientific communities to assess the state of knowledge in their fields and prepare recommendations for the next ten years. These surveys at once provide clear guidance for Agency decision making and also serve to build consensus within the highly diverse fields.

The Space Studies Board and its science discipline committees are the Enterprise’s principal independent source of strategic science advice. The Board and each of its six or so standing discipline committees meet three times or so times per year to work on assigned Enterprise advisory tasks.

Management Reviews

The NASA Strategic Management Handbook establishes that the Agency’s programs are to be overseen by a hierarchy of Program Management Councils (PMC). The Agency PMC at NASA Headquarters is responsible for evaluating proposals for new programs, for providing

approval recommendations to the Administrator, and for assessing programs of high visibility or cost to ensure that NASA is meeting its commitments. Other PMCs are established at the Enterprise level (EPMC), at the assigned project Center, at supporting NASA Centers, and at lower levels within each Center as required. Similar to the Agency PMC, these councils evaluate project cost, schedule, and technical content to ensure that NASA is meeting the commitments specified in the Program Commitment Agreement, the Program Plan, and the Project Plan.

The “governing” Program Management Council for a specific project is the highest level PMC that regularly reviews that given project. EPMC meetings are convened whenever major programmatic decisions are needed, such as for confirmation of a project to transition from Formulation to Implementation, or for termination reviews. In addition, monthly flight program reviews are held to assess program and project progress and performance against the program-level requirements, the cost plan, and the development schedule.

Various independent performance assessments are conducted by external teams throughout the life cycle and reported to the governing PMC.

Enterprise Strategic Planning

The Government Performance and Results Act (GPRA) requires NASA, as a federal agency, to submit an updated 5-year strategic plan every three years. The Space Science Enterprise develops its own enterprise plan on the same triennial schedule. Beyond supporting the Agency in meeting its statutory obligation, the Enterprise plan has many other valuable functions.

Audience	Enterprise Plan Function
OMB and Congress	Program and budget advocacy
External Science Community	Documentation for consensus on goals and priorities
NASA Agency Requirements	Input to Agency strategic plan and other GPRA documents
The Public	Handbook on NASA Space Science goals and plans
NASA Enterprises	Information for inter-enterprise collaboration
NASA Space Science Enterprise	Convenient reference for programmatic decision-making

The Enterprise strategic plan development process is dependent on the active involvement of outside parties, especially the space science research community. The National Research Council’s Space Studies Board and its discipline committees develop long-range strategic program assessments and recommendations. The SSAC, based on inputs from its own subcommittees, provides the Enterprise with roadmaps that integrate NRC and additional community inputs with technical, budget, and programmatic factors.

After the Enterprise assembles a draft strategic plan from these inputs, the draft is circulated to both the NRC and the SSAC for review and commentary. The result of this exhaustive process is a space science strategic plan that takes advantage of the best

- 1 specialized expertise available and represents a broad consensus of all parties engaged in
- 2 promoting the Nation's space science agenda.

A-4 GOALS, OBJECTIVES, AND RESEARCH FOCUS AREAS

Agency Strategic Goal	Space Science Theme	Space Science Enterprise Objective	Research Focus Areas
1. Understand the Earth system... to improve prediction of climate, weather, and natural hazards.	SEC	Understand the origins and societal impacts of variability in the Sun-Earth Connection.	<p>Develop the capability to predict solar activity and the evolution of solar disturbances as they propagate in the heliosphere and affect the Earth.</p> <p>Specify and enable prediction of changes to the Earth's radiation environment, ionosphere, and upper atmosphere.</p> <p>Understand the role of solar variability in driving space climate and global change in the Earth's atmosphere.</p>
	SSE	Catalog and understand potential hazards to Earth from space	<p>Determine the inventory and dynamics of bodies that may pose an impact hazard to Earth.</p> <p>Determine the physical characteristics of comets and asteroids relevant to any threat they may pose to Earth.</p>
5. Explore the solar system and the Universe beyond, understand the origin and evolution of life, and search for evidence of life elsewhere.	SSE	Learn how the solar system originated and evolved to its current diverse state.	<p>Understand the initial stages of planet and satellite formation.</p> <p>Study the processes that determine the characteristics of bodies in our solar system and how these processes operate and interact.</p> <p>Understand why the terrestrial planets are so different from one another.</p> <p>Learn what our solar system can tell us about extra-solar planetary systems.</p>
		Determine the characteristics of the solar system that led to the origin of life.	<p>Determine the nature, history, and distribution of volatile and organic compounds in the solar system.</p> <p>Identify the habitable zones in the solar system.</p>
		Understand how life begins and evolves.	<p>Identify the sources of simple chemicals that contribute to prebiotic evolution and the emergence of life.</p> <p>Study Earth's geologic and biologic records to determine the historical relationship between Earth and its biosphere.</p>
	Mars	Understand the current state and evolution of the atmosphere, surface, and interior of Mars.	<p>Characterize the present climate of Mars and determine how it has evolved over time.</p> <p>Investigate the history and behavior of water and other volatiles on Mars</p> <p>Study the chemistry, mineralogy, and chronology of martian materials.</p> <p>Determine the characteristics and dynamics of the interior of Mars.</p>

Agency Strategic Goal	Space Science Theme	Space Science Enterprise Objective	Research Focus Areas
		Determine if life exists or has ever existed on Mars.	Investigate the character and extent of prebiotic chemistry on Mars. Search for chemical and biological signatures of past and present life on Mars.
		Develop an understanding of Mars in support of possible future human exploration.	Identify and study the hazards that the martian environment will present to human explorers. Inventory and characterize martian resources of potential benefit to human exploration of Mars.
	SEC	Understand the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments.	Understand the structure and dynamics of the Sun and solar wind and the origins of magnetic variability. Determine the evolution of the heliosphere and its interaction with the galaxy. Understand the response of magnetospheres and atmospheres to external and internal drivers.
		Understand the fundamental physical processes of space plasma systems.	Discover how magnetic fields are created and evolve and how charged particles are accelerated. Understand coupling across multiple scale lengths and its generality in plasma systems.
	ASO	Understand how today's Universe of galaxies, stars, and planets came to be.	Learn how the cosmic web of matter organized into the first stars and galaxies and how these evolved into the stars and galaxies we see today. Understand how different galactic ecosystems of stars and gas formed and which ones might support the existence of planets and life.
		Learn how stars and planetary systems form and evolve.	Learn how gas and dust become stars and planets. Observe planetary systems around other stars and compare their architectures and evolution with our own.
		Understand the diversity of other worlds and search for those that might harbor life.	Characterize the giant planets orbiting other stars. Find out how common Earth-like planets are and see if any might be habitable. Trace the chemical pathways by which simple molecules and dust evolve into the organic molecules important for life. Develop the tools and techniques to search for life on planets beyond our solar system.
	SEU	Discover what powered the Big Bang and the nature of the mysterious dark energy that is pulling the Universe apart.	Search for gravitational waves from the earliest moments of the Big Bang. Determine the size, shape, and matter-energy content of the Universe. Measure the cosmic evolution of the dark energy, which controls the destiny of the Universe.
		Learn what happens to space, time, and matter at the edge of a black hole.	Determine how black holes are formed, where they are, and how they evolve. Test Einstein's theory of gravity and map space-time near event horizons of black holes. Observe stars and other material plunging into black holes.

Agency Strategic Goal	Space Science Theme	Space Science Enterprise Objective	Research Focus Areas
		Understand the development of structure and the cycles of matter and energy in the evolving Universe.	<p>Determine how, where, and when the chemical elements were made, and trace the flows of energy and magnetic fields that exchange them between stars, dust, and gas.</p> <p>Explore the behavior of matter in extreme astrophysical environments, including disks, cosmic jets, and the sources of gamma-ray bursts and cosmic rays.</p> <p>Discover how the interplay of baryons, dark matter, and gravity shapes galaxies and systems of galaxies.</p>
6. Inspire and motivate students to pursue careers in science, technology, engineering, and mathematics.	All Themes	Improve student proficiency in science, technology, engineering and mathematics using educational programs, products, and services based on NASA's unique missions, discoveries, and innovations.	
		Motivate K-16+ students from diverse communities to pursue science and math courses, and ultimately college degrees in science, technology, engineering, and mathematics.	
		Improve science, technology, engineering, and mathematics instruction with unique teaching tools and experiences that are compelling to teachers and students.	
		Improve higher education capacity to provide for NASA's and the Nation's future science and technology workforce requirements.	
7. Engage the public in shaping and sharing the experience of exploration and discovery.	All Themes	Improve the capacity of science centers, museums, and other institutions through the development of partnerships, to translate and deliver engaging NASA content.	
		Engage the public in NASA missions and discoveries through avenues in public programs, community outreach, mass media, and the internet	

A-5 THEME FLIGHT PROGRAMS

Solar System Exploration Missions

Missions in Implementation

Rosetta	ESA, launch 2003
Four US experiments	
Wirtanen rendezvous November 2011	
Deep Impact	NASA, launch 2004
Tempel 1 comet impact July 2005	
MESSENGER	NASA, launch 2004
Prime mission to Mercury 2009-2010	

Missions under Definition (Development in 2003-2008)

Dawn	NASA, launch 2006
Will orbit asteroids Ceres and Vesta	
Remote-sensing investigations on both	
New Horizons	NASA, TBD
Pluto-Kuiper Belt	
Netlander	CNES, launch 2007
Discovery MO	
Four small stations on Mars, 3 US instruments per station	
New Frontiers 1 and 2	NASA, 2009 and TBD
To be competitively selected	
Discovery 11 and 12	NASA, TBD
To be competitively selected	

Missions Under Study (Possible development beyond 2009)

First flagship mission: Europa Geophysical Explorer	NASA
New Frontiers 3 and 4	NASA, TBD
Competitively selected	
Discovery 13+	NASA, TBD
Competitively selected	

Mars Exploration Missions

Missions in Implementation

Mars Exploration Rovers (MER) **NASA, launch 2003**

MER-A launch May 2003, MER-B launch June 2003

Nominal missions of 90 Mars days beginning in January 2004

Mars Express **ESA, launch 2003**

US experiments: ASPERA-3 (space plasma and solar wind; Discovery MO) and MARSIS radar (subsurface structure)

Nominal mission December 2004-December 2005

Mars Reconnaissance Orbiter (MRO) **NASA, launch 2005**

Gateway reconnaissance for Scout 07/ MSL 09

Missions under Definition (Development in 2003-2008)

Scouts **NASA, launch 2007**

Four candidates in Phase A study

Final selection in August 2003

Mars Science Laboratory **NASA, launch 2009**

Mobile in situ exploration with emphasis on organics

Operate for 1 Mars year with radioisotope power system

US Telesat or Italian/NASA Science Orbiter **TBD, launch 2009**

Netlanders and TBD Orbital Science **NASA, launch 2009**

Sun-Earth Connection Missions

Missions in Implementation

Solar Terrestrial Relations Observatory (STEREO) **NASA, launch 2005**

Determine how coronal mass ejections originate and evolve

Stereoscopic measurements from 2 solar-orbiting spacecraft

Solar-B **ISAS, launch 2005**

Understand the life cycle of the magnetic field in the photosphere and how it couples to the corona

NASA providing components of 3 high-resolution solar

telescopes

CINDI

NASA, launch 2003

Determine the cause of plasma irregularities in Earth's upper atmosphere

TWINS

NASA, launch 2003 and 2005

First stereoscopic measurements of dynamic coupled 3-D structures in the magnetosphere

Missions under Definition (Development in 2003-2008)

Magnetospheric MultiScale (MMS)

NASA, launch 2009

Determine reconnection, particle acceleration and turbulence in the magnetosphere

Four-spacecraft tetrahedron

Geospace Electrodynamic Connections (GEC)

NASA, launch 2009

Understand how the ionosphere-thermosphere system responds to magnetospheric forcing

Four spacecraft measure conditions from very low perigee, "dipping" orbits

Aeronomy of Ice in the Mesosphere (AIM)

NASA, launch 2006

Small Explorer

Determine cause of highest clouds in Earth's atmosphere

Measure temperature and water vapor concentrations

Living with a Star Missions under Definition (Development in 2003-2008)

Solar Dynamics Observatory (SDO)

NASA, launch 2007

Determine what drives the solar variability that affects Earth

Ionospheric - Thermospheric Storm Probes

NASA, launch 2008

Determine what causes ionospheric variability/irregularity that disrupts communication

Radiation Belt Storm Probe

NASA, launch 2010

Understand how radiation belt particles that affect astronauts and spacecraft are injected, accelerated, distributed, and lost

Missions Under Study (Possible development beyond 2009)

Solar Probe, The First Voyage to a Star **NASA, TBD**

Determine the origin of the solar wind in the solar corona

In situ and remote sensing of the inner solar corona

Jupiter Polar Orbiter **NASA, TBD**

Compare magnetospheres of Jupiter and Earth

Image/measure Jupiter's auroral regions

Astronomical Search for Origins
Missions in Implementation

Space Infrared Telescope Facility (SIRTF) **NASA, launch 2003**
Stratospheric Observatory for Infrared Astronomy (SOFIA) **NASA, flight 2004**
HST Instruments **NASA, installation 2005**

Cosmic Origins Spectrograph (COS)

Wide Field Camera 3

Keck/Keck Interferometer **NASA, operational 2005**
Kepler **NASA, launch 2007**

Detect and characterize Earth-sized extrasolar planets by occultation

Discovery AO

Large Binocular Telescope Interferometer (LBTI) **NASA, 2006**
Missions under Definition (Development in 2003-2008)

Space Interferometry Mission **NASA, launch 2010**

James Webb Space Telescope **NASA, launch 2010**

Missions under Study (Possible development beyond 2009)

Terrestrial Planet Finder **NASA, TBD**

Filled Aperture Large Cooled IR Telescope **NASA, TBD**
Or
Large Aperture Optical/UV Telescope

Structure and Evolution of the Universe

Missions in Implementation

Galaxy Evolution Explorer (GALEX)	NASA, launch 2003
Swift Gamma Ray Burst Explorer	NASA, launch 2003
Gravity Probe-B (GP-B)	NASA, launch 2003
Astro-E2	ISAS, launch 2005
Planck	ESA, launch 2007
Co-manifested with Herschel	
Herschel Space Observatory	ESA, launch 2007

Missions under Definition (Development in 2003-2008)

Spectroscopy & Photometry of IGM Diffuse Radiation (SPIDR)	NASA, launch 2005
Small Explorers	
Gamma Ray Large Area Space Telescope	NASA, launch 2006
Joint with DOE	

Missions Under Study (Development date TBD)

Laser Interferometer Space Antenna (LISA)	NASA, TBD
Constellation-X	NASA, TBD

Missions under Study (Possible development beyond 2009)

Dark Energy Probe	NASA, TBD
Einstein Probe to determine the nature of dark energy	
Inflation Probe	NASA, TBD

Einstein Probe to test the inflationary hypothesis

Black Hole Finder Probe

NASA, TBD

Einstein Probe to perform a census of black holes in the Universe

1 A-6 ACRONYMS

1 **A-7 GLOSSARY**